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ANIMAL EXCRETA IN THE SUDAN GEZIRA

T. N. JEWITT AND H. W. B. BARLOW

(Research Division, Department of Agriculture and Forests, Anglo-Egyptian Sudan)

Introduction.—The area known as the Sudan Gezira is bounded by the Blue and White Niles to the east and west and extends southwards to about 13° 30′ N. The rainfall varies from 100 mm. at Khartoum to 500 mm. at Sennar. The soil is a heavy cracking clay (50 per cent. clay below 0·002 mm.) of high alkalinity (pH 9·0–9·5) with impeded drainage and high salt-content. Its total nitrogen-content is of the order of 0·03 per cent. in the top 2 ft. Agriculturally the most important part of the Gezira is the irrigated area to the east, watered from the dam across the Blue Nile at Sennar. The principal crops are long-staple cotton and sorghum. Data on yields quoted in this paper are all from experiments carried out on the Gezira Research Farm at Wad Medani (Lat. N. 14° 24′; Long. E. 33° 31′). Apart from the irrigated area, however, considerable crops of sorghum are grown under rainfall in other parts of the Gezira.

The principal manurial need of crops is nitrogen; phosphate and potash additions are of little importance. This is illustrated by the following summary of a series of replicated experiments performed by F. Crowther [1] on cotton crops over four seasons.

Yields of seed-cotton in lb. per acre

	O	P	K	PK	*Mean*
ON . . .	1,620	1,739	1,718	1,757	1,658
1N . . .	2,103	2,109	2,100	2,160	2,118
2N . . .	2,329	2,379	2,391	2,439	2,384

The fertilizer dressings per acre were 26 and 52 kg. N as ammonium sulphate, 34·5 kg. P_2O_5 as superphosphate, and 69 kg. K_2O as potassium sulphate. The average gain from nitrogen at the lower dressing is at the rate of 17·7 lb. of seed-cotton per kg. N.

The result of a 4-year experiment [2] comparing the response of cotton to cotton-seed cake and ammonium sulphate, each supplying 38 kg. N per acre, is given below:

Yields of seed-cotton in lb. per acre

Control	1,588
Cotton-seed cake . . .	2,079
Ammonium sulphate . . .	2,261

These figures demonstrate that the response to an organic manure is explicable on the basis of its nitrogen-content alone. These two manurial experiments were performed on the cotton phase of the rotation cotton–sorghum–resting land.

Sorghum under irrigation has also shown large increases in yield with nitrogenous manuring. For example, Crowther, in a 5-year experiment [2], obtained 192 and 376 per cent. increases with applications of 17·3 and 34·6 kg. per acre respectively of nitrogen as ammonium sulphate on a control yield of 293 kg. per acre of heads. The average gain from nitrogen at the lower dressing is at the rate of 33 kg. heads per kg. N.

In the experiments described below it has been assumed that the manurial value of animal excreta lies mainly in its nitrogen-content. It may be noted that this conflicts with the findings of Hartley [3] working in Northern Nigeria, where the main value of animal manure depends upon its phosphorus-content.

Although many field experiments have been made with dung, little attention has been paid to the quantity of nitrogen actually applied; the present paper attempts to provide relevant data by reporting on the nitrogen-content of dung excreted by cattle, sheep, and goats; the results of nitrification experiments with dungs and urines; and the responses to these materials in pot experiments.

Dung from penned animals.—In some preliminary experiments 10 mature sheep of varying ages in good condition were penned for 8 days and the dung collected daily. The sheep were of the type known locally as Butana from their district of origin. They were given a total of 214 kg. of dry matter, in the ratio of 10 pts. sorghum straw to 1 pt. hay from the legume *Dolichos lablab*, of which 72 kg. remained as uneaten residues at the end of the period.

Nitrogen-contents of each day's dung were measured on the air-dried material some days after collection. These showed a considerable fall during the experiment, from 1·83 to 1·20 per cent. expressed on an air-dry basis. In the light of later experiments there can be no doubt that the sheep had been previously fed on a diet of higher nitrogen-content than that fed during the experiment.

Further similar experiments were conducted with other sheep, goats, a dry cow, and a tillage bull, and the averaged results are given in Tables 1 and 2.

The bull lost weight on the first three diets and showed a considerable but incomplete recovery on the last two diets. The animal was not therefore on a maintenance ration, but it is obvious from the nitrogen supplied in the food and that excreted in the dung that the ratio of nitrogen in the dung to that in the urine varied over a very wide range. It is part of the intention of this paper to stress the importance of this ratio and the dependence of the manurial value of excreta upon the feeding of the animals.

Dung from field collections.—Samples of dry faeces of sheep and goats were taken from measured areas at a large number (20–50) of predetermined sites in each of five regions outside the irrigation scheme. The animals had been grazing on annual weeds during the rainy season and then on sorghum straw and perennial scrub. The samples were taken about 6 months after the rains when the livestock were being moved to the irrigated area to graze on cotton stalks. The mean nitrogen-contents of the faeces were 1·3 per cent. of dry matter and 0·3 kg.

per acre. An estimate of the annual deposition of nitrogen in faeces in the drier part of the unirrigated Gezira would be of the order of 0·4 kg. per acre.

Within the irrigated area the nitrogen in faeces was around 2·8 kg. per acre where sheep and goats were actually grazing on Dolichos and standing sorghum stalks, but much less where they were grazing on sorghum stumps and weeds. Over a large area near the Gezira Research Farm the amount of dung deposited between the rains of 1945 and 1946 was estimated to contain only 0·17 kg. of nitrogen per acre.

TABLE 1. *Amount of Air-dry Dung deposited and its Nitrogen-content for Animals on Different Diets*

Expt.	*Animals*	*Food*		*Per beast per day*		N, % *on air-dry dung*	N, *gm. per beast per day*
		Sorghum straw	*Dolichos hay*	*Food kg.*	*Dung kg.*		
1.	Mature sheep	10	1	1·8	0·10	1·47	1·5
2.	Sheep and lambs	0·8	1	1·56	0·24	1·58	3·8
3.	Goats and kids	2	1	2·05	0·08	1·73	1·4
4.	Goats and kids	..	Hay only	2·25	0·25	1·82	4·6
5.	Dry cow	2	1	8·4	0·84	1·38	11·6

TABLE 2. *Amount of Air-dry Dung deposited and its Nitrogen-content for a Tillage Bull on Different Diets*

Diet	*Kg. food consumed per day*		N, *gm. in food per day*	*Kg. dung per day*	N, % *on air-dry dung*	N, *gm. in dung per day*
	Sorghum straw	*Concentrate*				
1.	8·0	0	35	2·7	1·09	29
2.	11·2	0	48	2·7	1·01	27
3.	8·6	2	105	3·0	1·06	32
4.	7·0	4	184	3·9	1·12	44
5.	7·0	6	202	3·3	1·33	44

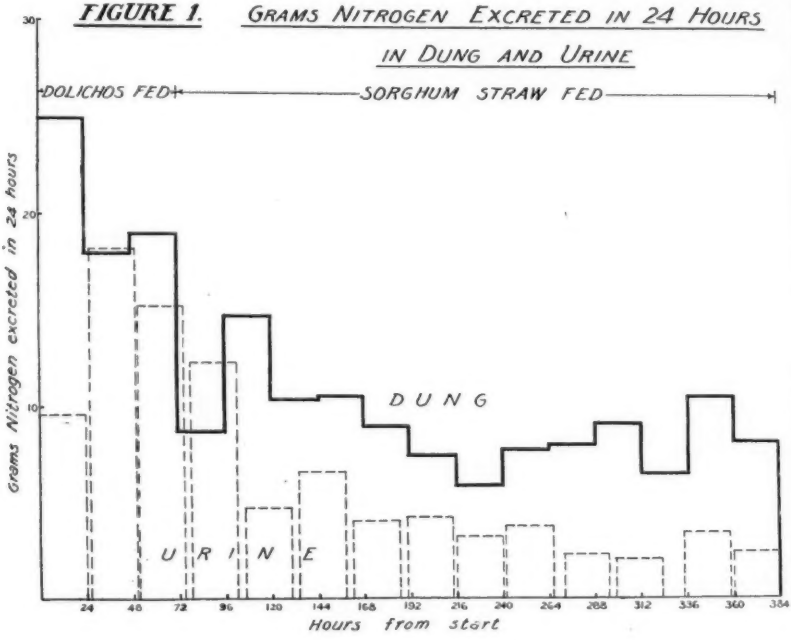
Comparison of nitrogen in dung and urine.—In assessing the manurial value of animal excretions it is obviously of great importance to obtain an estimate of the nitrogen in urine as well as in dung. When stall feeding is practised the two inevitably become mingled, but in the Gezira, beasts are rarely confined.

Separate estimates of the nitrogen in dung and urine were made on a Butana ram, 'Abu Bul', which was fitted with a container slung in a position to collect his urine.

The ram had been grazing on *Dolichos lablab* before the experiment, and was fed for the first 3 days on Dolichos hay; this was then replaced by sorghum straw. The results therefore are mainly applicable to sheep feeding on a low nitrogen diet, comparable with that generally offered to Gezira sheep. The collections of urine were made during complete periods of 24 hours; for the well-being of the animal these had to be separated by short resting periods of a few hours each. The urine was

removed three or four times daily from the collecting tin, and the nitrogen estimated in each lot. It was convenient to measure the nitrogen as grams per 100 c.c.

The results are plotted in Fig. 1 and mean values given in Table 3. The change of feeding after the first 3 days is reflected in the decreased excretion of nitrogen in both dung and urine. To obtain the ratio of nitrogen in dung to that in urine we have used the data of the last 9 days



of the experiment, during which time 9 days' dung was collected and 8 days' urine. In this preliminary experiment the food consumed by the sheep was not weighed and the necessity for improvements in technique were revealed.

A Managil ram, 'Kharuf', was fed on a measured diet of sorghum straw for 13 days immediately after he had been grazing on *Lippia nodiflora*, which is not considered to be good forage.

In this case longer resting periods were allowed, so again, urine and dung collections were not co-terminal. The nitrogen-contents of the successive collections of both dung and urine are given in Fig. 2A, and mean values in Table 3.

At the end of 'Kharuf's' diet of sorghum straw he was fed mixed Dolichos hay and sorghum straw in the ratio 1:3. Of this he ate the whole of the Dolichos, and the uneaten sorghum straw was removed and rejected once daily.

The nitrogen-contents of successive collections of urine and dung are given in Fig. 2 B. The periods of collection are continued from those in Fig. 2 A; it will be observed that the nitrogen excreted in urine showed a marked increase during the first 5 collections. We have used the values for the last 3 collections to calculate the ratio of nitrogen in dung to that in urine, the associated value for the nitrogen in dung being derived from the last 5 days (Table 3).

TABLE 3. *Nitrogen Excretion by Rams on Various Diets*

	Diet	*Mean* N *excreted, gm. per day*		*Ratio* N *in dung:* N *in urine*	*% of* N *in food accounted for in the excreta*
		In dung	*In urine*		
1. Ram A	Sorghum straw	8·2	3·2	2·6	..
2*a*. Ram B	Sorghum straw	5·24	3·97	1·32	93
2*b*. Ram B	Sorghum 3 : Dolichos hay 1	7·26	14·42	0·5	94
2*c*. Ram B	Dolichos hay only	13·1	25·6	0·51	91

The diet of the ram was then changed to one of Dolichos hay alone. The nitrogen-contents of successive 24-hour collections of dung and urine are given in Fig. 2 C. Throughout the feeding experiments with this ram its weight remained substantially constant at 75 kg.

The change in the ratio of N in dung to N in urine with changes in diet has also been observed with another smaller ram. In this case changes were larger: on a poorer diet of sorghum straw 80 per cent. of the nitrogen intake was excreted in the dung, on a diet of Dolichos hay 25 per cent. was recovered in the dung.

No direct measurements of the nitrogen excreted as urine by cows have been made, but we have data on the nitrogen-content of cow urine and of the amount of urine per urination obtained by manual collections. The following table summarizes the nitrogen-contents and the total nitrogen of the urines collected:

	N *gm./100 ml.*	*Total* N *gm.*
Cow in milk; morning (15 samples)	0·865	3·75
Cow in milk; afternoon (8 samples)	1·12	5·1
Dry cows; morning (14 samples)	0·644	3·9
Stock bull; morning (11 samples)	0·63	2·4

The cows were receiving concentrates, the bull was not. The largest excretion of nitrogen measured in a single urination was 10·3 gm. If this nitrogen were distributed without loss through 3 cu. ft. of soil, weighing 280 lb., the nitrogen addition is equivalent to 80 p.p.m.; this is to be compared with the normal total nitrogen of 300 p.p.m. in Gezira soil. In fact no such distribution is likely to take place until there has been nitrification and prolonged leaching, as usually the urine falls on dry soil and is absorbed on the surface-layer and on the walls of the deep cracks, which are a feature of the soil. As the urine dries there is considerable scattering of nitrogen-rich surface soil by animals, wind, and cultivation.

GRAMS NITROGEN EXCRETED IN 24 HOURS

IN DUNG AND URINE

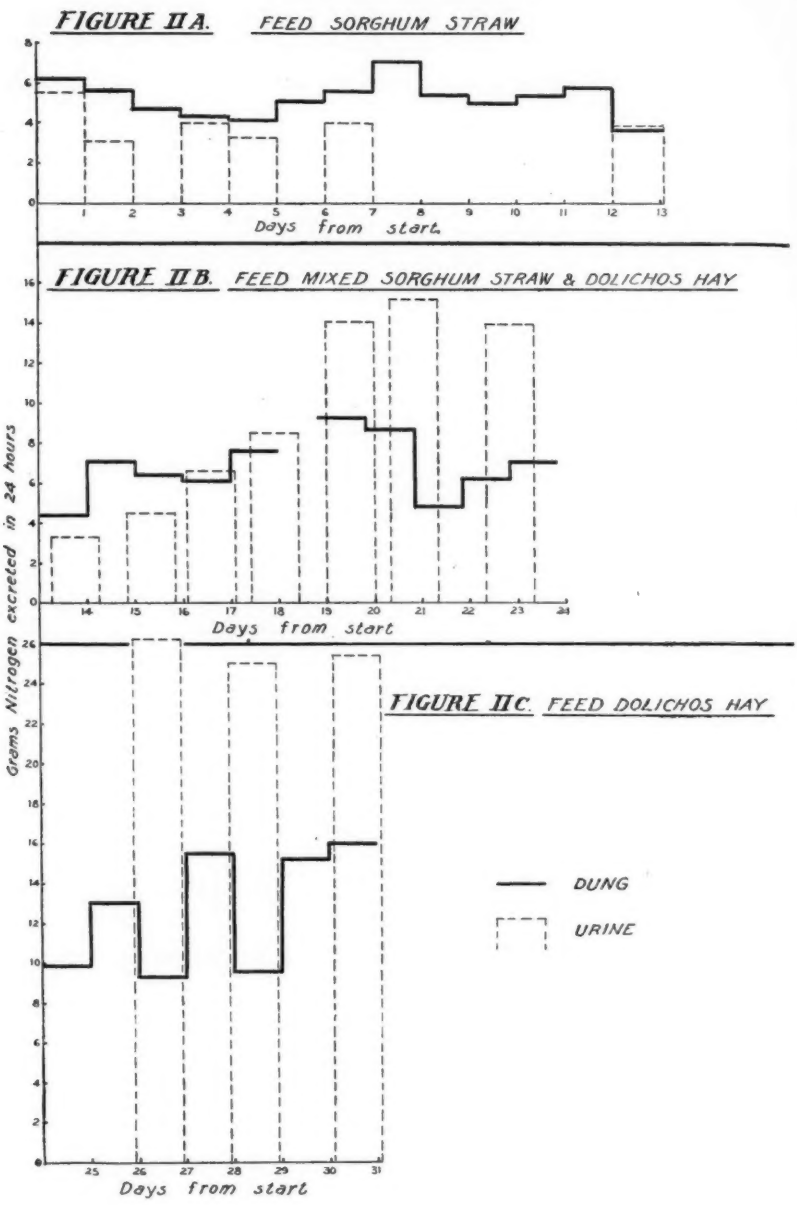


FIGURE IIA. FEED SORGHUM STRAW
Days from start.
FIGURE IIB. FEED MIXED SORGHUM STRAW & DOLICHOS HAY
Grams Nitrogen excreted in 24 hours
Days from start
FIGURE IIC. FEED DOLICHOS HAY
Days from start
DUNG
URINE

Nitrification Experiments

The nitrification of the nitrogen in various samples of dung has been studied in 25 gm. lots of soil kept at about the optimum moisture-content and room-temperature for varying periods, and the nitrate produced was estimated by extraction and the use of phenol disulphonic acid. Table 4 gives the results for some samples.

TABLE 4. *Nitrification of Cow, Sheep, and Goat Dungs in Gezira Soil*

Animal	N *in dung*, %	*Added* N, *p.p.m.*	NO_3–N *in p.p.m. after days shown below*							
			7	*13*	*22*	*28*	*34*	*40*	*48*	*57*
Cow . .	1·21	121	0·5	0·7	0·4	0·2	0·1	8	10	14
Sheep .	1·83	183	..	5	9	18	..	31	36	..
,, .	1·56	143	..	0·5	..	1	3	7	..	..
Goat . .	1·49	137	1	0·5	..	6	14	13	..	..
,, . .	1·91	130	0·5	0·5	..	0·5	..	7	..	..
No dung, soil alone	..	..	20	18	..	28	27	27	..	..

These nitrification figures for dungs of various origins do not show any consistent relationship between nitrification and nitrogen-content. It would ordinarily be expected that the dungs with the highest nitrogen-content would nitrify fastest, and with dungs of similar origin this is in fact the case, as is shown by the results in Table 5, which were obtained with samples of ram's dung collected during the feeding experiments described previously.

TABLE 5. *Nitrification of Sheep Dung*

N *in dung*, %	NO_3–N *in p.p.m. after days shown below*					
	0	*7*	*18*	*25*	*39*	*56*
1·04 . . .	..	1	1	1	1	1
1·15 . . .	..	1	1	1	1	1
1·64 . . .	..	1	1	1	14	20
1·97 . . .	..	1	8	9	42	55
2·14 . . .	..	1	25	36	80	84
No dung . .	12	24	25	24	40	34

The 25- and 39-day measurements were on single samples, the remainder were the means of two closely agreeing determinations on separately treated samples. It is clear from these results that dry dung releases available nitrogen very slowly, and indeed its application leads in many cases to a depression of nitrate concentration for several weeks.

The behaviour of urine in nitrification tests is quite different; very large amounts of nitrite and nitrate are produced in periods as short as a fortnight. Nitrification proceeds almost as rapidly as with ammonium sulphate, though the very large accumulations of *nitrite* measured have not been equalled in any of our work with ammonium sulphate.

Typical figures for urine nitrification follow in Table 6. The urine was applied both undiluted and diluted 1:5; the applications were all larger than those of the dungs.

TABLE 6. *Nitrification of Urine*

Sample A: *3,290 p.p.m. N added as undiluted urine*

Period (days) . .	4	5	7	9	11	12	14	17
NO_2–N p.p.m. .	3	3	60	170	165	700	900	800
NO_3–N p.p.m. .	1	3	6	10	24	22	55	240

Sample B: *2,100 and 420 p.p.m. N added as urine*

	Undiluted urine 2,100 p.p.m.				*Diluted urine 420 p.p.m.*				*No N added*			
	Days				*Days*				*Days*			
	8	*15*	*23*	*33*	*8*	*15*	*23*	*33*	*8*	*15*	*23*	*33*
NO_2–N p.p.m.	40	13	1	1	12	3	0	0	0	0	0	0
NO_3–N p.p.m.	11	410	1,180	1,600	60	155	350	470	24	27	25	31

Loss of ammonia from urine.—Soil treated with fresh urine was dried in a current of air, the ammonia removed being collected in acid. In such experiments the ammonia amounted to about 12 per cent. of the nitrogen in the urine for a single drying. In the field repeated wetting by rain would give renewed opportunities for loss. When soils treated with urine were repeatedly dried and re-wetted the total loss of ammonia reached 26 per cent.

The formation of large concentrations of nitrite during the nitrification of urine in Gezira soil offers a further possibility of loss through the decomposition of the nitrites.

Such losses of ammonia do not take place when cow dung is dried; samples of fresh dung lost only 1 per cent. or less of their nitrogen.

The possibility of loss of nitrogen as molecular nitrogen from dung has not yet been studied.

Pot Experiments

Eight pot experiments were performed with various samples of dung and urine, to estimate the response to these manures applied to Gezira soil. The test crop was radish.

Every experiment contained untreated controls and ammonium sulphate at the same rate of nitrogen as the manure being tested; in previous pot-work additions of nitrogen from 100 to 400 p.p.m. on air-dry soil gave marked increases in yield of radish, and the standard 'single dose' had been fixed at 100 p.p.m. N., which was 1 gm. ammonium sulphate per pot. There were usually 4 replicates.

In other pot experiments, a phenomenon was observed which greatly complicates the interpretation of the results which we describe below, namely, a depression in yield occurring when Gezira soil in pots is wetted for more than 5 days before sowing. The cause of this depression has

not been established, but the effect is evident in many of the treatments below, in which a period of wetting before sowing was given to allow nitrification of the manures to take place. This wetting reduces the response to ammonium sulphate itself, and tends to equalize the effects of all treatments. For this reason, in tabulating the results, the yields are shown in two ways in certain experiments: (*a*) as percentages of the unmanured controls not wetted before sowing; (*b*) as percentage increases in yield over unmanured controls within each wetting treatment. Drying the soil after this 'pre-wetting' treatment had been shown to result in a recovery, and this method of overcoming the difficulty was in some cases adopted, but, as the first experiment indicates, it was not entirely successful. However, the relative effectiveness of the dungs, urines, and ammonium sulphate is still clearly shown.

TABLE 7*a*. *'Gezira Dung'* (N *1·35 per cent.*) *and Effect of Drying out after Preliminary Wetting*

Dry-weight of radish tops as percentage of untreated control

		100 p.p.m. applied as	
	ON	*Amm. sulphate*	*Dung*
Not wetted before sowing	100	216	105
Wetted for 6 weeks before sowing . . .	82	96	71
Wetted for 6 weeks and then dried for 2 weeks before sowing	71	97	83

TABLE 7*b*. *Percentage Increase in Dry-Weight over Unmanured Controls in Each Wetting Treatment*

	Amm. sulphate	*Dung*
Not wetted before sowing . . .	116	5
Wetted 6 weeks before sowing . .	18	−13
,, 6 ,, and then dried 2 weeks .	36	16

The sample was a mixed one of sheep and goat dung, collected from a number of sites in the unirrigated area of the Gezira. It was finely ground, and mixed throughout the soil in the pot, 15·5 gm. being applied per pot.

It will be seen that the 2 weeks' drying after wetting did not at all overcome the deleterious effect of wetting, but the percentage increases due to additional nitrogen were higher than without the drying period, though in the case of the ammonium sulphate far lower than in the unwetted soil.

Two further experiments included this same dung and compared it with other samples of different nitrogen-content; the results are combined in Table 8.

The results demonstrate that on the average there was only a small response to medium- and low-nitrogen dungs, but that those with high nitrogen-contents were about half as good as ammonium sulphate. This accords well with the data given in Table 4.

TABLE 8. *Sheep and Mixed Dungs of Different Nitrogen-contents*

Percentage increase in dry-weight of radish tops over unmanured controls

Manure	N % in manure	N applied p.p.m.	
		100	200
A. Pots wetted 3 weeks and dried 2 weeks before sowing.			
Ammonium sulphate	21·00	30	89
Dung, mixed field	2·20	28	59
Dung, ram, rich diet	2·20	21	46
Dung, mixed field	1·35	13	22
Dung, ram, poor diet	1·10	0	22
B. Pots without preliminary wetting.			
Ammonium sulphate	21·00	46	61
Dung, mixed field	2·20	17	21
Dung, mixed field	1·35	8	13
C. Pots without preliminary wetting.			
Ammonium sulphate	21·00	92	131
Dung, sheep	1·60	3	30
D. Pots wetted 6 weeks before sowing.			
Ammonium sulphate	21·00	7	29
Dung, sheep	1·60	−7	16

Apart from the organic matter in dung, the mineral-content might be of value to plants, for, as noted on p. 2, it has been found elsewhere that phosphorus is the most important constituent of animal manure. The test crop in these pot experiments is sensitive to phosphorus added to Gezira soil, and an experiment was performed with goat dung containing N 1·58 per cent. and equivalent amounts of its ash, both by itself and with ammonium sulphate. Table 9 shows the results.

TABLE 9. *Goat Dung (1·58% N) and its Ash*

Percentage increase in dry-weight of radish tops over average unmanured controls

	Single application	Double application
(*a*) Ammonium sulphate	40	58
(*b*) Ammonium sulphate plus ash = dung in (*c*)	39	30
(*c*) Dung	7	17
(*d*) Ash = dung in (*c*)	−11	18

A single application of nitrogen was 100 p.p.m.
All pots were wetted for 6 weeks before sowing.

There was unfortunately considerable variation in this experiment, the unmanured controls ranging from 95 to 105 per cent. of the average. However, it is evident that the ash of the dung is of little or no value as a fertilizer, as under the conditions in treatment (*b*), with ammonium sulphate, it has caused no increase in yield, and it is here that it would be most likely to show up if its phosphorus or potassium were of any value. In an earlier pot experiment with this soil, radish showed an

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increase of 36 per cent. with 8 gm. of superphosphate per pot alone, as compared with 225 per cent. with 8 gm. superphosphate and 1 gm. ammonium sulphate per pot. Neither potash nor calcium gave any increase.

When we turn to the effect of urine the picture changes, and we find that this material is sometimes as good as, or better than, ammonium sulphate in increasing yield.

In an experiment with cow urine containing 0·89 per cent. N, we have data for the recovery of nitrogen by the plant (Table 10).

TABLE 10. *Percentage Increase in Dry-weight of Radish Tops over Unmanured Controls, and Percentage Recovery of Applied Nitrogen by the Whole Plant. Soils wetted Two Weeks before Sowing*

	N *added, p.p.m.*	*Increase of dry-weight,* %	*Recovery of nitrogen,* %
Ammonium sulphate . .	200	94	14
	400	222	15
Urine	200	44	6
	400	134	8

The percentage of nitrogen recovered from the urine was much less than from the sulphate of ammonia. In another experiment in which the soil was wetted for 3 weeks before sowing the responses were much smaller, only about 2 to 3 per cent. of the added nitrogen being recovered from either material.

In an experiment with sheep urine, the urine was in all cases diluted to 100 c.c., and poured on to the centre of the pot of soil, which was then either watered immediately and kept damp for 4 weeks, or the urine was covered by an inch of dry soil which 2 weeks later was watered and kept damp for 2 weeks. It will be seen in Table 11 that there was not a great reduction in the yield of the unmanured pots due to the extra 2 weeks' wetting, but that responses to manure were much lower. However, in both cases the urine was at least as effective as the inorganic fertilizer.

TABLE 11. *Dry-weight of Radish Tops as Percentage of Average Untreated Controls*

Weeks wetted before sowing		*Nitrogen applied, p.p.m.*		
		0	*100*	*200*
2	Amm. sulphate	100	200	239
	Urine		192	319
4	Amm. sulphate	91	114	197
	Urine		124	194

In another experiment sheep dung and urine were applied separately and together, to discover whether the easily available urine nitrogen would render the dung nitrogen available, or would itself be immobilized in the process of decomposition of the dung (Table 12).

TABLE 12. *Percentage Increase in Dry-weight of Radish Tops over Unmanured Controls*

Form of applied nitrogen	N *applied, p.p.m.*	
	84	*168*
Ammonium sulphate . . .	27	50
All as dung (1·14 per cent. N) . .	1	5
All as urine (0·35 per cent. N) . .	32	63
Half as dung and half as urine . .	6	23

All pots were wetted for 3, and dried for 2, weeks before sowing.

It will be seen that the responses to urine were as good as those to ammonium sulphate, but that the dung, which by itself gave no increase in yield (as would be expected from its low nitrogen-content) seems to have lowered the increase in yield attributable to the urine by about 10 per cent. It must, of course, be remembered that only half as much urine was applied in the mixed treatment.

The conclusion drawn from these pot experiments is that the urine is the part of animal excreta of greatest manurial value, whilst the dung, unless it is of high nitrogen-content, is of small value so far as immediate crop response is concerned. High-nitrogen dung is only found under natural Gezira conditions where the animals have been fed on Dolichos or concentrates.

Field Experiments

The laboratory results show that the widely held thesis that the major part of the manurial value of animal excreta lies in the urine obtains for Gezira conditions. On most diets the nitrogen in the urine is at least equal to that in the dung; nitrification experiments show that the urine nitrogen is readily nitrified, the reverse being true of dung, whilst our pot experiments have also shown the value of the urine.

We have many data from replicated field experiments which show that animal manure is effective in increasing yields of both cotton and sorghum under irrigation in Gezira soil. The measured increase in some of these experiments may be compared with expectation on the basis of the nitrogen-content of the excreta, using as standard the response to ammonium sulphate quoted in the introduction to this paper.

In the following experiments with tethered bulls the nitrogen in the excreta was calculated on the basis of the diet, assuming that this was a maintenance ration, and using accepted values for the nitrogen-contents of the food.

Bulls being fed 218 gm. nitrogen each per day were tethered on the plot for 3 consecutive nights, their numbers being such as to give 180 bulls per acre. If the rate of excretion were constant, the nitrogen excreted during the 3 nights would be 327 gm. per beast, equivalent to 58 kg. N per acre. These were working bulls receiving concentrates, and if the excreted nitrogen is divided between the dung and the urine in the ratio of 1 : 2, the calculated urine nitrogen per acre would be 38·6 kg. An increase in yield of cotton of 36 per cent. would be the expected

response to this weight of nitrogen applied as ammonium sulphate. The measured increase was 35 per cent. A similar increase was obtained in another experiment with the equivalent of 368 animals per acre. In both experiments there is no difficulty in accounting for the whole of the increased yield on the basis of the nitrogen in the urine.

In an experiment with sorghum, bulls were tethered in numbers equivalent to 82·5 per acre, and with the same assumptions as before 18 kg. N per acre would be applied as urine. The increase in yield was 798 kg. heads per acre on a control yield of 897 kg. per acre. The increased yield with 18 kg. N applied as ammonium sulphate in an earlier experiment was 594 kg. heads per acre. The increase observed from tethering bulls could therefore be largely accounted for by the nitrogen in the urine.

In another tethering experiment, in this case by the late F. Crowther [4], tillage bulls were tethered for 2 and 4 nights at the rate of 35 bulls per acre. Dry cows receiving a lower nitrogen diet were also included in the experiment. Each treatment was divided into two, in one of which the dung was removed by hand whilst in the second it was left. The yields are set out below:

Yields of Sorghum Heads in kg. per Acre

Animals tethered	*Dung left*	*Dung removed*
1. Dry cows, 4 nights .	820	830
2. Bulls, 2 nights . .	930	851
3. Bulls, 4 nights . .	1,187	1,097
No animals	673	

If the average response of sorghum to nitrogen in sulphate of ammonia is taken from earlier manurial experiments (33 kg. heads per kg. N) it is possible to compare estimates of the amounts of nitrogen in urine with those to be added as sulphate of ammonia to produce the same yields. In estimating the urine nitrogen from dry cows receiving only 160 gm. of N per day, it was assumed that only half of this nitrogen reached the urine.

	Estimated nitrogen in urine, kg. per acre	*Nitrogen in estimated equivalent of sulphate of ammonia, kg. per acre*	
		Dung left	*Dung removed*
1	3·6	4	5
2	5	8	5
3	10	16	13

The estimates agree fairly closely and support the view that the manurial effect is due almost entirely to the urine. They also show that there was a small additional effect from the dung of working bulls receiving concentrates, but not from the dung of dry cows. It happens that the dung collected from the 'dung removed' sub-plots was weighed and

applied in an unreplicated experiment to land coming under sorghum. There it gave no increase in yield, although there was a considerable response to the urine left behind.

In all the experiments with cattle described above no account has been taken of the uneaten residues of the diet. These residues are in fact mostly of the roughage portion of the diet, and they are therefore not of the first importance from the point of view of the excreted nitrogen. Since, however, they were left on the plot they would most likely have a depressive effect on the yields. The necessity of using tillage animals for work during the day makes it unavoidable that they can only be used for manurial experiments at night, so that the amount of nitrogen excreted on to the plots is uncertain; this difficulty is not encountered with sheep.

In a sheep-penning experiment on sorghum, designed by F. Crowther [4] and carried out by M. C. Hattersley, sheep were folded on sub-plots so that there were approximately 1,600 sheep per acre receiving 3,730 kg. dry sorghum straw and 700 kg. of dry Dolichos hay per acre, containing altogether 24 kg. of nitrogen. Taking 50 per cent. of this as being in the urine there was an application of 12 kg. of urine-nitrogen per acre. The increased yields of heads corresponded to those from 11 kg. N per acre as sulphate of ammonia in earlier experiments.

In an experiment designed by M. A. Bailey and H. Greene and started in 1936–7, sheep were folded on the plots and fed a fixed ration of 3,730 kg. sorghum straw and 700 kg. Dolichos hay per acre containing 24 kg. of nitrogen per acre. Sheep were also included in the experiment on the same diet with the addition of cotton-seed cake containing the equivalent of 26 kg. nitrogen per acre.

Yield of Seed-cotton in lb. per Acre

Control	1,310	percentage	100
Fixed ration	1,560	,,	119
Fixed ration plus cotton cake .	1,740	,,	132

Using our previous assumptions as to the division of nitrogen between dung and urine as 50 and 67 per cent. in the urine for the poorer and richer diets respectively, the applications of urine-nitrogen are 12 kg. per acre and 33 kg. per acre. If the average response of cotton to nitrogen in sulphate of ammonia is taken as 18 lb. of seed-cotton per kg. of N, the inorganic equivalents of the two folding treatments would be 14 and 24 kg. per acre, which agree roughly with those calculated from the feeding stuffs.

The results of these field experiments clearly demonstrate that important increases in yield are obtained from the application of animal manure. The nitrogen in the diet was in all cases derived by using accepted figures for the nitrogen-contents, not by actual determinations of the food.

Discussion

In attempting to correlate these experimental results with the value of animal manure in the area of commercial cotton-growing it is important to remember that the general animal population does not receive

concentrates. The chief forage crops in the Gezira irrigated area are sorghum straw and Dolichos—the latter usually grazed, but the animals also graze on cotton plants when picking of the crop is completed. With this in mind perhaps the most valuable of the field experiments is that in which dry cows receiving only Dolichos hay and sorghum straw were used, for this is the case where the application of nitrogen most closely resembles that found in general in the irrigated area. There is, however, an important difference between experimental applications and the situation in the field. In the experimental area the manurial treatments were applied to land soon to be cropped, whereas outside, the rotation adopted always provides either 1 or 2 resting years before each crop of sorghum or cotton. The main application of manure is therefore to land about to enter a resting period, during which there will normally be weed-growth, and in the year before the land comes under crop it receives manure only from animals which have grazed on these weeds. Measurements of the density of dung deposition where animals were grazing on standing sorghum straw and Dolichos (p. 3) gave the considerable figure of 2·8 kg. nitrogen-in-dung per acre. This, however, is still very much lower than experimental applications. Measurements on land where there was only casual grazing on cotton plants, sorghum stumps, and weeds gave the very small value of 0·17 kg. per acre. From comparison with the responses in field experiments it is clear that animal excreta on land where standing crops have been grazed is of considerable potential value. How much of this value is lost in the weed-growth that follows the deposition of the excreta is not known, but it is likely to be considerable, as the nitrogen absorbed by weed-growth is not readily returned to the land. The potential value of the manure is also reduced by the circumstance that considerable quantities of the sorghum straw are not consumed on the field.

In the unirrigated areas of the central Gezira the dung nitrogen was estimated to be of the order of 0·4 kg. per acre (p. 3). Here in a normal year, with sorghum growing under rain, a smaller response to nitrogen would be expected than under irrigation, and with an application of 0·4 kg. N per acre as dung, only a trifling immediate response could be looked for from the associated urine.

In the irrigated area the potential value of the nitrogen excreted by animals can be arrived at from the available feeding-stuffs.

The areas of irrigated crops in 1945–6 were:

Cotton . . .	204,000	acres
Sorghum . .	130,000	,,
Dolichos . . .	45,000	,,
	380,000	,,

The nitrogen-content of sorghum straw per acre is of the order of 3 kg., that of Dolichos per acre of the order of 23 kg. The nitrogen in these two crops is therefore 1,400,000 kg. This is 3·7 kg. per acre of the total *cropped* land. On the basis that one-half of the sorghum nitrogen and two-thirds of that of the Dolichos is excreted as urine, the total urine nitrogen excretion is 2·1 kg. per acre of cropped land. The division

of the nitrogen between the dung and the urine is based on the results of the feeding experiments with the rams, when the weights of the animals were held approximately constant. The figure is therefore a maximum. Such an amount of nitrogen applied as sulphate of ammonia should give an increase of 37 lb. per acre in the yield of seed-cotton, and 75 kg. per acre in the yield of sorghum heads. It is evident that the smaller area under Dolichos makes a larger contribution to manurial value than the larger area of sorghum.

There are no modern data on the number of animals in the Gezira, but a rather old series of figures is available for the animal population of the Blue Nile Province of which the Gezira is part. For the whole Province there are 0·69 sheep and goats per acre. Combining the data on the nitrogen in sheep and goat dung per animal per day (p. 3) to obtain a figure of 1·0 kg., the annual deposition of nitrogen in sheep and goat dung throughout the Province is 0·69 kg. per acre. The urine nitrogen is probably of the same order. There is undoubtedly a concentration of animals in the irrigated area, so that the average figure there would be higher. Since within this area there is a further concentration on the land which has grown sorghum and Dolichos, the measured value (p. 5) for such land of 2·8 kg. of nitrogen in dung is perhaps in reasonable accord with the value for the whole Province of 0·69 kg. per acre.

Animal manure finds a secondary use as fuel, and convenient accumulations are frequently burnt. The practice is readily understandable, for fuel is in very short supply in the irrigated Gezira. As a fuel used in place of wood, dung is fairly satisfactory so far as its calorific value is concerned. Values of 6,050, 6,920, and 6,550 B.T.U. have been determined on three samples of dung. The existence of this alternative use of dry dung and the system of uncontrolled grazing makes it unlikely that any measure of dung collection for manure could be instituted, nor is it likely that the cultivators could be persuaded to scrape up urine-impregnated earth from the few places where there is a worth-while accumulation. Such sites do occur at watering-places, and in fact the accumulations there present a noteworthy reduction in the amount of excreta usefully deposited on cropped land.

These considerations all lead to the conclusion that animal excreta make only a small contribution to the fertility of the irrigated Sudan Gezira. Field and pot experiments and the result of laboratory nitrification experiments all show that the urine is the vehicle of the readily available nitrogen, whilst the dung, except where containing an unusually large percentage of nitrogen, makes only a minor immediate contribution of mineral nitrogen. It may well be that the dung makes a contribution to the fertility through its organic-matter content, but we have no experiment which demonstrates that this is true.

Summary

This paper describes a series of experiments bearing on the amount and availability of animal manure in the dry and irrigated parts of the Sudan Gezira. Special emphasis is placed on the influence of the diet

on the effectiveness of the manure, and on the paramount importance of the urine.

Responses to animal manure have been measured in pots and in the field. Collections of dung and urine have been made from penned animals, and laboratory tests done on the rates of nitrification of such excreta. Dungs have been collected from many sites in the field, and the amounts deposited per year have been estimated; from these data deductions have been drawn as to the potential value of the animal manure in the region.

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THE RELATION BETWEEN THE SIZE OF FIELDS AND THE SPREAD OF PLANT-DISEASES INTO THEM

PART II. DISEASES CAUSED BY FUNGI WITH AIR-BORNE SPORES; WITH A NOTE ON HORIZONS OF INFECTION

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IN this part we set out to demonstrate three points: that making fields larger and correspondingly fewer, without change of shape, aspect, or uniformity of distribution, decreases the movement of fungus spores by air between them; that this decrease is not offset by an increased multiplication of infection within the enlarged fields, provided that they are homogeneous at the start; and that, although some spores travel and remain alive over very long distances, there is in certain circumstances a fairly close horizon of infection about a field from beyond which a negligible amount of infection is received. This last point is in answer to the question: Is making fields larger and correspondingly fewer a method applicable by a small group of neighbours, or must it be practised on a continental scale to be effective? The question is pertinent to all attempts at sanitation, rather than to the enlargement of fields in particular; but since it does not seem to have been answered before, it must be discussed here.

It is necessary to know the gradient of infection away from its source; and the discussion can fortunately be simplified because it is concerned only with the fairly large distances between fields, not the short distances usually travelled by spores within fields. For these fairly large distances we estimate the probability that a spore will settle at a distance x from its source empirically as

$$p = \frac{k}{x^n} \qquad (1)$$

in which k and n are constants.

To evaluate n one may refer to Gregory's collection of data from the literature of observed gradients of infection from a *point* source [1, Fig. 4]. For distances over 30 m., values of n run at 2 or more. With the only two fungi observed over a distance of more than 100 m., n tends to a value of about 4. We shall therefore work on the assumption that over appropriately long distances n is greater than 2 and may even approach 4. We may also interpolate here that in the only two sets of data for *Phytophthora infestans*, a fungus to be discussed in Part III, n tends to a value of 4 as the distance from the source increases.

Treatment of n as a constant is possibly inaccurate even when x is large, but is justifiable here, first, because the records are too meagre for better treatment and, secondly, because it is adequate for the limited purpose of this discussion.

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The Effect of making Fields Larger and Proportionately Fewer on the Movement of Spores between them

Assume here that the fields are uniformly distributed over the country. Making them uniformly larger and correspondingly fewer increases the average distance between them, downwind or in any other direction, in proportion to the square root of their average area, their shape and aspect being unchanged. A cloud of spores travelling with the wind will pass first one field, then another, and so on, becoming more and more dilute as it travels. Consider a single spore. The average distance, not necessarily on a straight course, it must travel from any particular relative position in the field of its origin to any particular relative position in the first field it reaches is proportional to the square root of the average area of the fields, that is, it must travel an average distance $k_1 A^{\frac{1}{2}}$, where k_1 is a proportionality constant and A the average area of the fields. The probability of it settling at any particular single point in the first field is therefore, by equation (1), $k/k_1^n A^{\frac{1}{2}n}$. The average distance the spore must travel to cross the first field, that is, the average number of potential settling points the spore has in its track across the field, is also proportional to the square root of the average area. The probability that the spore will settle somewhere on its track across the first field is therefore $kk'/k_1^n A^{\frac{1}{2}(n-1)}$, where k' is another proportionality constant. Similarly, if the spore passes the first field, the probability that it will settle in the second it reaches is $kk'/k_2^n A^{\frac{1}{2}(n-1)}$; that it will pass the first two fields and settle in the third, $kk'/k_3^n A^{\frac{1}{2}(n-1)}$; and so on. The probability that the spore will settle in one or other field it reaches after leaving the field of its origin is therefore

$$p = \frac{kk'}{A^{\frac{1}{2}(n-1)}}\left(\frac{1}{k_1^n}+\frac{1}{k_2^n}+\frac{1}{k_3^n}+\ldots\right).$$

The series

$$\frac{1}{k_1^n}+\frac{1}{k_2^n}+\frac{1}{k_3^n}+\ldots$$

may be taken as convergent when $n > 1$, because it is almost identical with the series

$$\frac{1}{k_1^n}\left(1+\frac{1}{2^n}+\frac{1}{3^n}+\ldots\right),$$

which is convergent when $n > 1$. Hence,

$$p \propto \frac{1}{A^{\frac{1}{2}(n-1)}} \quad (n > 1).$$

The probability that a spore will settle in one or other field after leaving the field of its origin is also the proportion of spores that moves from one field to another. Accepting this meaning of p demonstrates our first point in the circumstances we postulate: that the fields are uniformly distributed and enlarged without change of shape or aspect.

Effect of the Enlargement of Fields on the Multiplication of Infection within them

We accept our second point—that enlargement of fields is not accompanied by increased multiplication of infection within them, provided that they are homogeneous at the start—as a matter of direct observation.

Large diseased fields can be expected to lose a somewhat smaller proportion of spores than small fields, because a greater proportion of the spores which are released fall back within the field. If this somewhat greater falling-back of spores appreciably increased the multiplication of diseases within the fields, gradients of disease would inevitably follow, even though the fields at the start were homogeneous. Potato-fields, for example, would die of blight, and wheat-fields of rust in a direction against that of the prevailing wind. If the direction of the wind was variable, infection would dwindle towards the edges of the fields. Moreover, to affect the point of our discussion to any significant extent, these gradients would have to be pronounced. Small irregularities do occur in the infection of fields for one reason or another, but anything like regular, pronounced gradients of this sort are absent, both in small fields and in large; were these gradients present, they would inevitably be observed, and their occurrence would long ago have been accepted by plant pathologists as a regular phenomenon of plant disease. (We exclude from these remarks small border effects which sometimes extend inwards for a few feet; and consequently our remarks do not apply to small plots a few square feet in area.) We accept therefore that the somewhat greater retention of spores in enlarged fields is without influence on the multiplication of disease.

Horizons of Infection

With crowd diseases a farmer, or small group of neighbours, may check the movement of infection by making fields larger and proportionately fewer without much concern about what is happening 10 miles away; for with crowd diseases infection does not travel far in considerable amount. But with many fungi with air-borne spores the matter is not so simple. *Puccinia graminis* moves from Mexico to Canada in a season [2]; and although making wheat-fields larger and proportionately fewer over the N. American continent would have the effect of delaying the appearance of the black rust in Canada, there is small consolation in this thought for the Canadian farmer, because the continent-wide control of the size of fields is not within the present scope of practical politics. All that he can hope for is that some change in organization, farm machinery, or economics brings about an enlargement of fields without increasing the total area under cultivation, and thus achieves the desired results incidentally.

Even delicate spores often travel great distances: live spores of *Phytophthora infestans* are carried 30 to 40 miles by wind under favourable meteorological conditions [3], and in the 1840's this fungus sped across the potato fields of Europe with what must have been very brisk strides.

If *Phytophthora infestans* moves so swiftly, can a farmer reasonably expect to gain much by the local destruction of a few infected heaps of cull potatoes [4]? Is any form of local sanitation of value with fungi

which spread far and quickly? We must answer this because, as a method of sanitation, making fields larger and correspondingly fewer is usually applicable only on a restricted local scale. There are two extremes to consider:

1. *Horizons about a field in a uniformly infected area.*—To take the simplest case, suppose there are a number of uniform fields uniformly scattered over a large area. Consider any one of them. The mean distance (for the purpose of good approximation we neglect deviations from the mean) a spore must travel from 2 fields away is twice the distance from a neighbouring field. The probability that it will arrive and settle is, by equation (1), $1/2^n$ of the probability that a spore will arrive from a neighbouring field and settle. But in any direction the mean number of spores released 2 fields away is twice that released in neighbouring fields. Hence the mean number of spores received from 2 fields away is $Q/2^{n-1}$, where Q is the number received from immediately neighbouring fields. Similarly the mean number from 3 fields away is $Q/3^{n-1}$; and so on. The total number received by the field from all other fields, however distant, is therefore

$$Q\left(1+\frac{1}{2^{n-1}}+\frac{1}{3^{n-1}}+\ldots\right).$$

If $n = 2$, or less, this series is divergent; and there is no horizon from beyond which the amount of infection is negligible. If $n > 2$, the series is convergent; a horizon is established however far live spores may travel.

If $n = 2{\cdot}5$, 38 per cent. of the spores reaching the field come, on an average, from its immediate neighbours, 40 per cent. come from more than 3 fields away, and 32 per cent. from more than 5 fields away. If $n = 3$, the respective figures are 61, 17, and 11 per cent.; if $n = 4$, 83, 3, and 1 per cent. If one regards 10 per cent. of the infection coming from beyond the horizon as negligible, then if $n = 2{\cdot}5$, a horizon is established more than 50 fields away; if $n = 3$, about 5 fields away; and if $n = 4$, 2 fields away. From this it is clear that although $n > 2$ is the mathematical condition for a horizon, no horizon close enough to be of much use exists until $n = 3$, or more.

2. *The horizon about a healthy field in a healthy area threatened with infection.*—The importance of infection coming into an area depends on its amount relative to the amount already present in the area. Any amount of infection, however small, coming into a healthy area is important, and, if infection can travel far, there can be no horizon of infection about a healthy field. Infection is limited only by the distance over which it can travel, and the value of n is important only in so far as it affects this distance.

Long-distance migrations of fungi in a short period are all from diseased to healthy, or nearly healthy, areas: the movement of *Puccinia graminis* northwards in N. America, or the spread of *Phytophthora infestans* over Europe a century ago are examples which have been already mentioned.

It follows, too, that it is impossible by methods of hygiene to maintain for long a *completely* healthy area in a region in which infection is moving over considerable distances.

The scope for local hygienic measures.—One is usually concerned with something between the two extremes just discussed. If by some hygienic measure infection is reduced within the horizon of infection about a field, the reduction of infection necessarily brings about an extension of the horizon, and the process eventually defeats itself. The matter need not be discussed in much detail. If n is small, the horizon is sensitive to changes in the amount of infection, and small reductions of infection by local attempts at hygiene bring about conditions for infection to flow in from outside. But if n is large—if, for example, $n = 3$, or more—the horizon is both close and fairly insensitive; and a considerable reduction of infection should be possible by a group of neighbours without it being neutralized almost immediately from elsewhere.

The determination of n, whether its value is constant or a function of x or other variables, is thus of great importance in practical plant pathology. It probably depends to a very great extent on the climatic conditions that prevail while spores are being dispersed; and there may be a hint in the fact that both fungi, *Phytophthora infestans* and *Peronospora schleideniana* (*P. destructor*), for which there are some indications that n approaches 4, need humid conditions for their spread.

Summary

Over distances long enough to be appropriate to the movement of infection between fields, the probability of a spore settling and causing infection at a distance x from its source is determined approximately and empirically as $p = k/x^n$, where k is a constant and n, determined from records for dispersal over distances greater than 30 m., has a value of at least 2 and sometimes approaches 4.

If fields are made larger and correspondingly fewer, without change in shape, aspect, or uniformity of distribution, the proportion of spores transferred from field to field varies inversely as $A^{\frac{1}{2}(n-1)}$, where A is the average area of the field.

This gain through enlargement is not offset by increased multiplication within the fields.

Irrespective of how far spores can travel, it should be possible to use this method of enlargement of fields, or any other hygienic measure, on a local scale with partial success, provided $n = 3$ or more.

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THE THREE-QUARTER-BRED HOLSTEIN-ZEBU HEIFER

PART III. THE AGE OF PUBERTY

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THE age at which Holstein-Zebu heifers reach puberty, under conditions of adequate nutrition and good management, is unknown. Peasant-owned cattle of similar genetic type are bred for the first time at an age considerably more advanced than is usual in temperate-zone husbandry. Two possible causes of delayed puberty exist: it may be the outcome of slow rearing on an inadequate plane of nutrition, or it may be a consequence of the Zebu component of their ancestry. A combination of both factors may be responsible.

Owing to the high rearing costs of Holstein-Zebu [1], it was of interest to determine the earliest age at which pregnancy could be induced with safety. Since the nutritional demands of the foetus during the first 6 months of pregnancy are low, considerable saving in rearing costs could be effected by early breeding without imposing too severe a strain on the dam.

The term puberty is used in the present communication to mean the age at which the first conception culminating in a clinically recognizable pregnancy could be induced.

Experimental

The animals used were the 17 three-quarter-bred Holstein-Zebu heifers described in Parts I and II of the present series of communications [1, 2]. To prevent stunting of the heifers it was decided not to breed any animal until 17 months of age when, it was felt, about two-thirds of adult size would have been attained. Accordingly no animal was served until that age irrespective of signs of heat appearing earlier.

The bulls used were cross-bred Holstein-Zebus of the Government Stock Farm stud. These bulls were in regular service in the Stock Farm commercial herd and some had been at stud on the Department of Agriculture's breeding-stations throughout the colony. Their records with other cows showed that they were all fertile. To guard against incompatibility between individual males and females when a heifer failed to settle to a service a different bull was usually used at the next service.

The heifers were under careful daily supervision, close observation for signs of heat being kept.

The general management and feeding during this period were described in Part II [1].

Results

The breeding records are given in Fig. 1. The number of points shown for each heifer indicate number of services and the age of the

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heifer at each service. The last point in each case represents the service which resulted in pregnancy. No case of abortion occurred. The value given after the last point for each heifer is her live-weight at the time of the successful service.

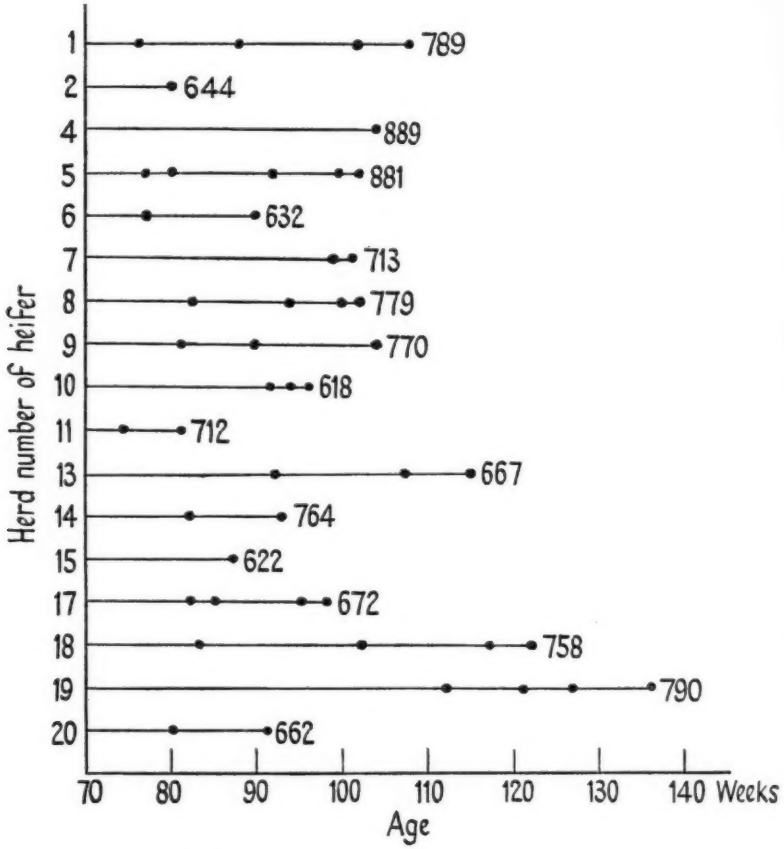

FIG. 1. The relation between age, weight, and puberty in three-quarter-bred Holstein-Zebu heifers. The points shown for each animal indicate services, the final point representing the service which culminated in pregnancy. The value given after the final service in each case is the weight of the heifer at the time of conception.

Several animals showed signs of heat before they were 17 months of age. However, such signs were not evidence of sexual maturity; in one case only, No. 2, did conception follow the first service after reaching 17 months of age. In the two animals, Nos. 4 and 15, signs of heat were not observed until they were 24 and 20 months of age respectively, when they settled to a single service. In the remainder from 2 to 5 services

were needed for conception. The intervals between successive heat periods were very irregular in duration. In one case only, No. 10, did the successive heat periods fall in cycles of approximately 3 weeks duration.

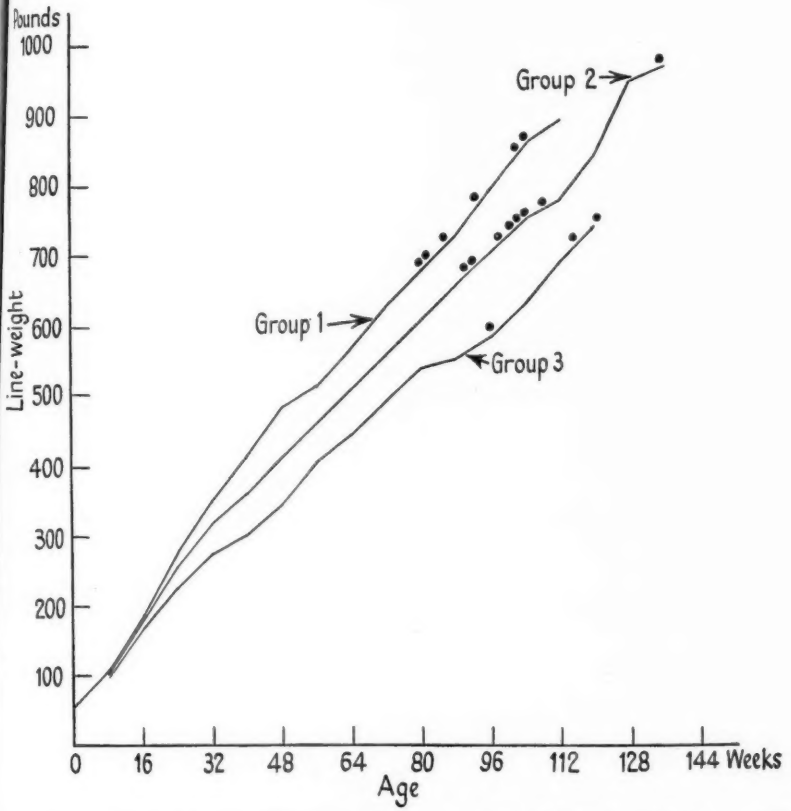

FIG. 2. Average live-weight-curves of three groups of heifers divided according to weight at 2 years of age. The points plotted above each curve represent the ages at which individual members of the group reached puberty.

The age at which puberty was reached did not bear a close relation to body-weight. The lightest weight at which conception occurred was 622 lb., the heaviest was 889 lb. Two-thirds of the heifers were over 700 lb. live-weight before reaching puberty. The average weight of heifers at puberty was 727 lb.

The relation between age of puberty and rate of growth is given in Fig. 2. The heifers are divided into three groups according to their rates of growth. Group 1 contains those animals, Nos. 2, 4, 5, 11, 14,

and 15, which had reached body-weights between 800 and 900 lb. at 2 years of age. Group 2 contains those animals, Nos. 1, 6, 7, 8, 9, 17, 19, and 20, which had reached weights between 700 and 800 lb. at 2 years of age. Group 3 contains those animals, Nos. 10, 13, and 18, which had reached 600 to 700 lb. at the same age. The curves given represent the average weights at different ages for each group. The ages at which individual members of each group reached puberty are indicated as points plotted above the corresponding weight-curve.

The earliest conceptions occurred in Group 1. Three animals of this group reached puberty before the first pregnancy occurred in Group 2. However, the remaining three animals of Group 1 did not reach puberty until much later. The latest age to reach puberty was at 136 weeks of age for an animal, No. 19, of Group 2. Although two heifers in Group 3 were among the last to reach puberty, one animal, No. 10, conceived at 96 weeks of age.

Discussion

The late age at which puberty occurs in Holstein-Zebu heifers is interesting. The average age of puberty in *Bos taurus* breeds is given by Hammond [3] as 9 months, with a range of 5 to 15 months. Data correspondingly extensive for Zebu are lacking, but some results of interest are given by Littlewood [4]. In his studies of improved Nellore cattle he noted that the average age of first calving was 3 years and 4 months, compared with 4 years to 4 years and 6 months for unimproved peasant-owned Nellores. If his animals were bred as early as possible the age of puberty in Nellores under good management and nutrition would thus be about 2 years and 7 months. The average age of puberty of 1 year and 11 months in Holstein-Zebus, where the Zebu blood came from the use of Nellore foundation dams, represents a considerable reduction from the age of puberty of the parent breed. However, the age at which sexual maturity is reached in Holstein-Zebus remains considerably higher than in Holsteins. This is surprising in view of the closer genetical relation of Holstein-Zebus to Holsteins than to Nellores. On the other hand, such comparisons may be false to some extent. Comparison between Holstein-Zebus and Holsteins leaves out of account the difference in environment. It is uncertain whether Holsteins would reach puberty at so early an age under climatic conditions such as exist in Trinidad.

The wide range of ages at which puberty is reached in Holstein-Zebus is also of interest, particularly since the group used was not large in number. The range was from 1 year and 7 months to 2 years and 7 months and is greater than Hammond's range for all temperate-zone breeds combined. However, it is interesting to observe that most of the cases were concentrated in the lower part of the range. Thus 13 of the 17 heifers reached puberty by the age of 2 years and, of these, 5 reached puberty by 1 year 9 months of age. It is not yet known whether early sexual maturity is an inherited characteristic in Holstein-Zebu cattle, but if this is so, considerable opportunities for improvement by selection for early maturity exist. In a breeding-programme for the

improvement of Holstein-Zebus only a relatively small number need be rejected on the basis of slow sexual development.

Compared with tropical-zone breeds the development of the capacity to reproduce is delayed to a much later stage of growth in Holstein-Zebus. The retardation of sexual development is greater than can be accounted for by slowing down of growth and is, presumably, a manifestation of Zebu characters. The average live-weight of heifers at puberty was 727 lb., a value considerably higher than the weights of temperate-zone breeds at the time of puberty. The average weight of Holstein heifers at 9 months of age is 509 lb. [5]. As was stated in Part II, the general appearance and weight of the present cross-bred heifers suggest that their adult size will be approximately that of Guernsey cattle. In this breed the weight at puberty is 389 lb. [5]. As temperate-zone dairy stock are not bred until they reach the age of about 15 months the difference between live-weights at the time of the first conception are materially reduced. Thus the weights of Holsteins and Guernseys at this age are 746 and 584 lb. respectively.

Although more rapidly growing Holstein-Zebu heifers tended to reach puberty earlier than slow-growing animals, the differences were insufficiently distinct for rapid early growth to serve as an index for selection in any breeding-programme.

Summary

The average age of puberty in three-quarter-bred Holstein-Zebu heifers was 1 year and 11 months with a range of 1 year and 7 months to 2 years and 7 months.

Although rapidly growing heifers tended to reach puberty before slowly growing animals, there was no close relation between weight and age at sexual maturity.

The average weight at puberty was 727 lb.

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ASCORBIC ACID IN CABBAGES

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ALTHOUGH numerous studies on the ascorbic-acid content of cabbages have appeared recently in the literature [1, 2], certain aspects treated in work carried out in these laboratories some time ago do not appear to have been developed by other workers. In particular the relationship between size and ascorbic-acid content, to which attention was drawn in a preliminary communication on tomatoes [3], has been found to hold good.

Methods of analysis.—Preliminary studies showed the dehydroascorbic acid in fresh cabbage tissue to be less than 10 per cent. of the total ascorbic acid. It was consequently neglected, and all determinations were made by the direct titration with 2.6.dichlorphenol-indophenol. The only difference from the method already described [4] was that in all cases a solution of metaphosphoric acid was used as extractant for the ascorbic acid. This solution was made in the earlier work from glacial metaphosphoric acid, but later by dissolving the requisite amount of phosphorus pentoxide in ice-water.

Distribution of ascorbic acid in leaf and head.—The distribution of ascorbic acid in the outer, intermediate, and inner leaves of a single head of All-Seasons cabbage, picked 24 to 36 hrs. before analysis, and stored in the refrigerator until required, was investigated with the results shown in Table 1.

Thus the blade is richer in ascorbic acid than the midrib, whatever part of the head the leaf comes from. There is no regular trend in ascorbic acid from the base towards the tip, but the difference between blade and midrib appears to be greatest for the outermost leaf.

To investigate any difference due to the position of the leaf in the head, groups of leaves taken in sequence from each of three cabbage-heads were sampled. The heads were of the All-Seasons variety, picked from the field the previous day. Taking each cabbage separately, the leaves were arranged in order from the outside to the inside of the head, the core forming the final section. The leaves from each head were then divided into 7 groups of equal numbers taken in succession, and a sample for analysis from each group was obtained by taking three cork-borer samples (of $\frac{3}{4}$ in. diameter) through the stack of leaves (Table 2).

Although the group of leaves in which the minimum ascorbic acid-content is reached varies from head to head, the trend is in every case the same: the highest figure is shown for the core, and a progressive fall through the heart leaves to somewhere in the intermediate groups, followed by a rise in the outer group. The mean figures show that the heart leaves, core, and outer leaves are significantly higher than all the

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rest, which do not differ significantly amongst themselves. The heart leaves and core are also significantly richer than the outer leaves. The loss of ascorbic acid caused by the practice of discarding the outer leaves is consequently fairly large.

TABLE 1. *Distribution of Ascorbic Acid within the Cabbage Leaf (in mg. per 100 grams)*

Outside green leaf:	Midrib, base	77·5
	„ tip	82·9
	Blade	109·0
	„	100·9
Outside green leaf:	Midrib, base	76·3
	„ tip	84·9
	Blade	95·9
	„	88·4
Mid leaf:	Midrib, base	86·6
	„ next to base	82·5
	„ next to tip	80·1
	„ tip	82·4
	Blade, base	88·5
	„ next to base	86·0
	„ next to tip	80·1
	„ tip	90·6
Inner leaf:	Midrib, base	86·6
	„ tip	85·3
	Blade, base	92·3
	„ tip	91·3
Inner leaf:	Midrib, base	82·3
	„ tip	83·1
	Blade, base	93·2
	„	92·7

TABLE 2. *Distribution of Ascorbic Acid among the Leaves of the Cabbage*

Part of head	*Ascorbic acid in mg. per 100 gm.*				*Weight as per cent. of total*
	Head I	*Head II*	*Head III*	*Mean*	
Core	121·2	111·1	117·4	116·6	10·6
1st group of leaves	94·2	85·0	103·2	94·1	0·7
2nd „ „	71·1	65·0	78·1	71·4	2·1
3rd „ „	69·1	59·4	62·5	63·7	6·3
4th „ „	71·6	57·4	62·6	64·0	15·2
5th „ „	73·8	59·7	59·4	64·3	20·4
6th „ „	75·6	64·7	59·1	66·5	22·8
7th group—the outside leaves	75·9	88·9	63·6	77·5	21·9

Difference for significance between two means 12·07 mg. per 100 gm.

Sampling procedure.—To avoid the stripping procedure, an attempt was made to use the samples taken with a cork-borer from entire heads. Double cork-bore samples taken at intervals of 45° around the equatorial plane of a cabbage-head gave the following results (Table 3):

TABLE 3. *Ascorbic-acid Content of Samples taken with a Cork-borer (mg. per 100 gm.)*

Sector	*Ascorbic-acid content*	*Sector*	*Ascorbic-acid content*
0°	69·1	180°	68·6
45°	67·0	225°	67·9
90°	69·4	270°	69·0
135°	70·2	315°	70·0

As long as the cork-bore samples are kept on the one plane, variation from this source seemed sufficiently small to be neglected. The agreement obtained between duplicate samples was not less satisfactory than was obtained by shredding the entire cabbage with a sharp knife to allow mixing before sampling, as has been commonly reported in the literature. Our results were (mg. per 100 gm.): Sampled by cork-borer, 55·7 and 54·8; sampled by shredding, 53·6 and 51·8.

Diurnal variation of ascorbic acid in young cabbages.—Several workers have shown that the concentration of ascorbic acid in the leaves of green plants is affected by the light received [5], and even that it fluctuates during the day. In the case of cowpeas [6] the latter effect has been proved to be due to concurrent variations in moisture-content. In our studies no significant effect was obtained when 16 cabbage seedlings were analysed at 9.30 a.m. and another 16 at 4.0 p.m., their ascorbic-acid content being 70·7 and 69·2 mg. per 100 gm. and the difference necessary for significance being 5·74 mg. For these plants the moisture-content was virtually the same, being 93·2 per cent. and 93·3 per cent. respectively. To avoid any interference from a diurnal effect, all cabbage-heads for which data are reported subsequently in this paper were harvested between 9.0 a.m. and 9.30 a.m., and stored in the dark at less than 4° C. until analysed.

TABLE 4. *Effect of Maturity on the Ascorbic-acid Content of Cabbages*

Weeks after planting out															
2		*4*		*6*		*8*		*11*		*15*		*19*		*23*	
Wt. Head	*Asc. acid*	*Wt. Head*	*Asc. acid*	*Wt. Head*	*Asc. acid*	*Wt. Head*	*Asc. acid*	*Wt. Head*	*Asc. acid*	*Wt. Head*	*Asc. acid*	*Wt. Head*	*Asc. acid*	*Wt. Head*	*Asc. acid*
gm.	mg.	gm.	mg.	gm.	mg.	gm.	mg.	gm.	mg.	gm.	mg.	gm.	mg.	gm.	mg.
2·1	159·1	0·5	221·7	4·3	138·8	2·2	176·0	15	152·3	720	102·0	1,070	90·3	1,890	48·4
0·4	224·8	0·6	199·7	2·6	139·7	1·2	149·8	280	117·5	317	97·2	1,335	60·5	2,920	50·4
1·5	145·1	1·6	169·5	15·9	120·5	2·7	158·3	97	120·7	610	94·3	2,165	53·5	2,580	45·8
1·6	183·9	2·1	161·3	7·2	127·5	10	122·3	107	128·6	260	100·4	1,760	61·8	2,080	75·0
0·4	211·4	1·1	206·3	3·9	171·8	19	141·0	19	140·8	90	137·4	1,445	51·0	1,780	60·8
1·7	187·2	2·3	169·2	4·3	159·2	11	154·6	69	108·3	217	107·3	1,580	65·4	1,630	64·5
1·2	195·0	3·3	156·2	1·4	185·9	17	166·5	132	121·5	267	83·0	1,230	77·3	2,550	60·4
0·8	174·9	5·6	135·4	5·3	147·9	23	167·2	60	113·8	325	104·1	1,550	88·1	1,360	47·0
1·2	185·1	2·1	177·4	5·6	148·9	10·7	154·4	97·3	125·4	351	103·2	1,517	68·5	2,099	56·5

Difference for significance of two means, 20·04 mg. per 100 gm.

Effect of maturity.—Cabbage seedlings of the Succession variety were planted out in the University grounds on June 8, 1943, at 2 months old. Eight plants were selected at random at successive intervals throughout the growing-period for analysis. For the first three samplings the whole plant was taken for analysis; at the fourth the plants were cut in half if

they were too large for analysis; at the fifth and sixth the leaves were stripped from the plants, arranged each time in a pile and cork-bore samples taken through them. At subsequent samplings the method outlined above was used.

The figures show a very marked decline in the ascorbic-acid content as the plants progress from the seedling stage to maturity. This trend is accompanied in every age-group by a tendency for the smallest plants picked to have higher ascorbic-contents and the larger plants to have lower ones. When plotted against each other, the mean ascorbic-acid content and the time since planting out give almost a straight-line relationship.

Effect of time of picking on ascorbic-acid content.—Superimposed on the continuing decline in ascorbic-acid content with age is the influence of picking-time once the cabbages reach maturity. The means for six heads of mature cabbages harvested on each of three dates are given below.

TABLE 5. *Effect of Time of Picking on Ascorbic-acid Content*

Date picked	*Mean head-weight*	*Mean ascorbic-acid content*
	gm.	mg. per 100 gm.
27.10.43	1,207	50·6
2.11.43	1,280	60·5
7.11.43	1,628	55·1

Difference between two means for significance at the 5% point = 8·5 mg. per 100 gm.

Thus there is a significant difference between the mean ascorbic-acid content of the heads harvested on October 27 and those on November 2, although the mean weight of heads (and the range of weights) were approximately the same. The difference between the samples harvested on November 2 and 7, which in any case is not significant, could be associated with the larger weight of the later sample. This interaction of effects is discussed below. The difference shown between the heads harvested on the first two dates may be due to differences in the quantity of light energy received immediately before harvesting. The light energy received on each of the 14 days before these dates was calculated[1] from the hours of bright sunshine recorded at Sydney, and from the 12-year results of the relation between Solar Radiation and the daily Hours of Bright Sunshine (Table 6).

The greatest absolute difference between the picking-dates is shown for the 7 days before sampling. Expressed as a percentage of that received by the first picking, the greatest difference is, however, shown by the 5-day figures, when it is 50 per cent. of that received by the first picking, compared with the 37 per cent. increase shown on the 7-day figures. As will be shown later, the solar radiation received for the 7-day period appears to be more significant.

[1] By the late W. B. Rimmer of the Mount Stomlo Observatory, Canberra, A.C.T.

TABLE 6. *Variation of Solar Radiation received with Date of Picking*

Length of period	*Solar radiation received in a specified period prior to*		*Absolute difference in solar radiation received*
	27.10.43	*2.11.43*	
1 day before	514	401	−113
2 days ,,	852	873	21
3 ,, ,,	1,061	1,253	189
4 ,, ,,	1,302	1,829	527
5 ,, ,,	1,612	2,421	809
6 ,, ,,	2,077	2,944	867
7 ,, ,,	2,518	3,458	940
8 ,, ,,	3,100	3,796	696
9 ,, ,,	3,598	4,005	407
10 ,, ,,	3,724	4,246	522
11 ,, ,,	4,137	4,556	419
12 ,, ,,	4,651	5,021	370
13 ,, ,,	5,092	5,462	370
14 ,, ,,	5,368	6,044	676

Effect of variety, size of head, and solar radiation received, on the ascorbic-acid content of mature heads.—Cabbages of the three varieties Early Jersey Wakefield, Copenhagen Market, and Succession were grown in the University grounds during 1943. These varieties were chosen because the shape normally found represented three distinct types, namely, the heart-shaped, the flattened, and the normal round head. Savoy cabbages were also grown but owing to the depredations of pests, insufficient heads were harvested for comparisons to be of value. For the other three varieties the ascorbic-acid content, the weight of each individual head, and the solar radiation received in the 7 days before harvesting are given in Table 7.

Further consideration of the data suggests some relationship subsists between the weight of the head and its ascorbic-acid content. The correlation coefficients and linear regression coefficients between these quantities for each variety are given in Table 8. The regression coefficient is negative for all three varieties, i.e. as the weight increases the ascorbic-acid content falls. The magnitude of the regression coefficient diminishes as the mean head-weights become larger, the coefficient for Early Jersey Wakefield being significantly larger than the coefficients for the other two varieties, which do not differ between themselves.

The results given in Table 9 show that the partial regression coefficients obtained for solar radiation over the 7 days before picking, is more significant than that obtained for the 5-day period.

From these results it appears that the solar radiation received in the 7 days before picking has a very significant effect upon the ascorbic-acid content of the mature head. The coefficient for head-weight also shows a better relationship for the analysis using 7-day radiation than for that using the 5-day radiation, but is not significant. This is in contrast with the significant correlations shown for two of the varieties, when considering the relationship only *within* varieties. This implies that the

TABLE 7. *Ascorbic-acid Content, Head-weight, and Solar Radiation received before Harvest for all Mature Heads analysed*

Early Jersey Wakefield			*Copenhagen Market*			*Succession*		
Ascorbic acid	*Head-weight*	*Solar radiation*	*Ascorbic acid*	*Head-weight*	*Solar radiation*	*Ascorbic acid*	*Head-weight*	*Solar radiation*
mg./100 gm.	gm.	gm. cal./cm.²	mg./100 gm.	gm.	gm. cal./cm.²	mg./100 gm.	gm.	gm. cal./cm.²
44·6	485	2,788	65·1	1,325	2,586	49·2	940	2,518
52·6	435	,,	50·4	1,930	,,	51·0	1,160	,,
55·6	475	,,	43·5	1,230	,,	51·8	1,140	,,
53·0	855	,,	50·2	1,540	,,	61·6	920	,,
65·1	255	,,	41·8	1,520	,,	48·9	1,520	,,
63·2	404	,,	49·1	1,150	,,	41·1	1,560	,,
49·3	440	,,	44·1	1,210	,,	66·0	1,070	,,
47·9	955	,,	45·1	1,760	,,	52·7	800	,,
56·0	335	,,	55·6	1,150	,,	70·5	1,030	,,
58·2	570	,,	51·6	1,750	,,	50·0	1,260	,,
45·5	750	,,	53·1	2,040	,,	53·9	1,160	,,
49·5	780	,,	41·1	4,190	,,	44·1	1,880	,,
52·3	420	,,	51·9	1,140	3,458	42·1	780	,,
53·8	410	,,	57·2	1,370	,,	50·1	2,030	,,
42·9	750	,,	72·6	640	,,	50·9	1,990	,,
43·8	865	,,	60·1	1,240	,,	45·5	2,340	,,
45·8	385	2,850	61·7	1,290	,,	68·9	680	3,458
38·4	540	,,	49·6	2,080	,,	68·3	1,150	,,
46·8	580	,,	53·6	950	,,	49·8	900	,,
49·1	700	,,	55·9	1,500	,,	59·6	1,250	,,
57·8	325	,,	61·7	1,820	,,	59·4	1,530	,,
72·3	295	,,	52·5	2,190	,,	57·1	2,170	,,
51·2	385	,,	..	..	..	45·7	1,690	3,400
51·7	340	,,	..	..	..	66·7	2,160	,,
54·0	360	,,	..	..	..	51·1	1,830	,,
47·2	425	,,	..	..	..	54·7	2,020	,,
49·0	390	,,	..	..	..	56·1	1,040	,,
48·2	1,005	,,	..	..	..	56·6	1,090	,,
68·7	350	,,	..	..	..	69·7	1,240	,,
45·6	460	,,	..	..	..	58·4	1,420	,,
41·8	425	,,	..	..	..	48·4	1,890	2,956
48·1	745	,,	..	..	..	50·4	2,920	,,
..	..	..	..	..	..	45·8	2,580	,,
..	..	..	..	..	..	75·0	2,080	,,
..	..	..	..	..	..	60·8	1,780	,,
..	..	..	..	..	..	64·5	1,630	,,
..	..	..	..	..	..	60·4	2,550	,,
..	..	..	..	..	..	47·0	1,360	,,
Mean:								
51·04	529	2,819	53·07	1,592	2,982	55·36	1,540	2,944

TABLE 8. *Correlation and Regression Coefficients for Head-weight and Ascorbic Acid*

Variety	*Correlation coefficients*		*Regression coefficients*	
Early Jersey Wakefield .	0·5689	sig. at 1% point	−0·02237	sig. at 1% point
Copenhagen Market .	0·4563	,, 5% ,,	−0·00514	,, 5% ,,
Succession . . .	0·3516	N.S.	−0·00630	N.S.

TABLE 9. *Partial Regression Coefficients of Head-weight and Solar Radiation received on the Ascorbic-acid Content of the Mature Head*

Quantity	*Coefficient*	*d.f.*	*Signif. of Coeff.*
(i) Weight	−0·000575	82	$0{\cdot}7 > P > 0{\cdot}6$
Solar radiation in previous five days .	0·008026	7	$0{\cdot}02 > P > 0{\cdot}01$
(ii) Weight	−0·001314	82	$0{\cdot}3 > P > 0{\cdot}2$
Solar radiation in previous seven days	0·009044	7	$0{\cdot}01 > P > 0{\cdot}001$

ascorbic-acid content is affected by variety as well as by head-weight and solar radiation. That this is so can be seen from the analysis of covariance (Table 10), which shows a significant difference between the ascorbic-acid content of the different varieties.

TABLE 10. *Analysis of Covariance of Head-weight and Solar Radiation on Ascorbic Acid*

Source	*Sums of squares*	*d.f.*	*Corrected sums of squares*	*d.f.*	*Variance*	*Variance ratio (F)*
Between varieties	259·2343	2	477·8646	2	238·9323	4·300
Within varieties	5960·3757	89	4833·7680	87	55·5606	..
Total	6219·6100	91	5311·6326	..	..	..

Using the coefficients derived from the analysis of covariance, the mean ascorbic-acid content for each variety has been calculated from the mean head-weight and mean solar radiation. From these data comparison can be made between the ascorbic-acid content actually found and the ascorbic-acid content that should have been found if only head-weight and solar radiation were the determining factors, and variety was without effect (Table 11).

TABLE 11. *Comparison of the Ascorbic-acid Contents of the Three Varieties with those calculated from the Regression Equation derived from Table 10*

Variety	*No. of heads analysed*	*Ascorbic acid (mg./100 gm.)*		*Difference between (A–B)*	*Diff. for signif.*
		Found (A)	*Calculated (B)*		
Early Jersey Wakefield	32	51·04	55·52	4·48	3·80
Copenhagen Market	22	53·07	52·42	0·65	4·66
Succession	38	55·36	52·46	3·90	3·47

It can be seen that the mean ascorbic-acid content of Early Jersey Wakefield is significantly lower than would have been expected from its small size, whilst that of Succession is significantly higher.

Discussion

If the hypothesis can be advanced that ascorbic acid is present in higher concentrations in tissues of greater metabolic activity, the relationships obtained above might be predicted. Thus in considering the distribution of ascorbic acid in the cabbage head, concentration would be greatest either in the actively dividing cells of the young inner leaves and growing-point, or in the outer leaves, which absorb most of the radiation from the sun (Tables 1, 2). Extending this to the effects of maturity, the

weight-change with age is accompanied by a marked inverse relationship between mean weight and mean ascorbic-acid content, and the latter effect is also seen within the eight heads which constitute each sample (Table 4). On the hypothesis advanced, this could be explained as follows.

In the seedlings the proportion of total weight represented by cells in a state of rapid division is at a maximum. At this stage also all the leaves are exposed directly to the sun. The ascorbic-acid content under these conditions reaches its highest value. As the plants age, the ascorbic acid declines as the proportion of actively dividing tissues declines. This is represented by the period between the 2nd and 15th weeks after planting out, when a 300-fold increase in weight was accompanied by a decline in ascorbic-acid content from 185 to 103 mg. per 100 gm., i.e. a decline to slightly more than half of its original value. As soon as the leaves begin to interlock with each other and hearting takes place, the ascorbic-acid content falls proportionately more rapidly. The reduction in the proportion of actively dividing tissues is continuing during this period, whilst in addition the interlocking of the leaves shields the inner leaves from solar radiation to a progressively increasing extent. During this period from 15 to 23 weeks after planting out, the ascorbic-acid content declined again to slightly more than half its value at the beginning of the period (from 103 to 56·5 mg. per 100 gm.) for only a six-fold increase in the weight of the heads.

For mature cabbages, the proportion of the total weight of the head represented by the growing tip and by the outermost leaves will change but slightly for considerable increases in head-weight. The metabolic activity of the growing tip will remain relatively constant, but the activity of the outer leaves would be expected to vary with the quantity of radiant energy falling upon them. It would consequently appear that the ascorbic-acid content of mature cabbage heads would be much more markedly affected by the solar radiation received prior to picking than it would be by changes of head-weight: essentially the same conclusion arrived at by the statistical analysis of the experimental results quoted here.

Summary

A study has been made of the effect of certain factors on the ascorbic-acid content of cabbages, and of its distribution within an individual head.

The ascorbic-acid content was found to be highest in the heart-leaves and core, and high in the outer leaves, with a zone of minimum concentration occurring between these two.

The mean ascorbic-acid content for the cabbage falls progressively from the seedling stage to the mature head, the decline being more rapid after hearting has taken place.

The solar radiation received before picking has been found to have a very significant effect on the ascorbic-acid content of the mature heads, whilst for two of the three varieties studied a significant negative correlation was found between the weight of the head and its ascorbic-acid content.

A significant difference has been found between the mean ascorbic-acid contents of the three varieties used, which remains even after the effects of varying solar radiation and head-weight have been removed.

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BREEDING FOR MILK IN A MEDITERRANEAN ENVIRONMENT

PART II: GOATS

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THE eastern Mediterranean has for centuries been an area in which goats flourished and were kept extensively. The free-range type of goat is met with in all Mediterranean countries from Turkey, through Syria, Palestine, and Egypt to Algeria and Morocco. Goats will find a living where sheep will not, but the two animals are also found in composite flocks in many of these countries. This paper, however, is concerned not so much with the free-ranging or flock goat as with the dairy-type or tethered goat which is increasing in importance as a dairy animal in these countries, particularly in Cyprus.

The 'tethered' goat is really a misnomer, for tethering is merely a form of restraint applied to any goat which has become more domesticated and less dependent on free-range habits than the ordinary native goats. Not all tethered goats, however, are of improved dairy type or breed. Nevertheless, this term is in general use in Cyprus and therefore the term 'tethered' goat will be used in the present paper to describe the hand-fed, household type of goat, as distinct from the free-range type. The term 'dairy' goat will be used for milch breeds generally. The paper deals with work carried out in Cyprus on the improvement of the dairy type of goat and in particular with the work done at the Government Stock Farm between 1930 and 1947.

Distribution and importance of goats.—The total number of goats in Cyprus and the countries bordering the eastern Mediterranean and the percentage of goats to the total sheep and goat population is given in Table I. Thus the proportion of goats to sheep varies in the different countries, and their numbers indicate their relative importance. With the exception of the Angora goat in Turkey, where about one-third of the total is represented by this breed, goats are primarily kept for milk.

TABLE I. *Goat Populations in the Middle East*

Country	*Total number of goats (latest figures)*	*Percentage of goats to total sheep and goats*
Cyprus . . .	224,000	40
Egypt . . .	755,000	33
Palestine . .	380,000	76
Transjordan . .	440,000	66
Syria . . .	800,000	27
Turkey . . .	14,000,000	45

Milk production and management, however, vary considerably and few data on breeds and milk yields are available, though in the Jewish settlements in Palestine, as well as at the Palestine Government farms,

comparatively high yields have been obtained. Generally speaking, lactation yields for dairy goats may be said to vary from about 250 lb. up to 1,500 lb., higher yields being exceptional. Of the various dairy breeds of goats the Damascus, Mamber, and Maltese are among the best, the Damascus, described by Hirsch [1] as 'the richest milk-yielding breed throughout the entire Near East', having distinct possibilities as a dairy goat for this part of the world. Saanen and Anglo-Nubian goats have been imported into Palestine and the former have done well on a limited scale and under specially good management [2].

In most countries the ordinary native free-range goat is regarded by many agriculturalists and forest officers as a nuisance and responsible for much damage to forest and fruit-trees. There is, no doubt, some truth in this contention, but, as Maule [3] has shown, the free-range goat is useful on account of its low maintenance costs, and because it can find a living on scrub-land that is incapable of producing a crop except in the form of goat's milk, meat, and skin. It seems reasonable to assume, therefore, that the ordinary free-range goat still has a role to play in these countries but that by better management its harmfulness can be controlled. Development in goat husbandry, however, is likely to be concerned more with the dairy goat, the importance of which as a milk producer in peasant farming is now becoming recognized.

Development of goat husbandry in Cyprus.—Until about 1930 there was little record of any official encouragement of, or interest in, tethered-goat husbandry in Cyprus. The few good goats in the island were probably derived from importations from Asia Minor, Egypt, and Malta some 40 to 50 years earlier, although there is no definite record of such introductions. Census figures for dairy goats show that they have increased from just under 15,000 in 1939 to nearly 36,000 in 1946, representing 15 per cent. of the total goat population in that year [3].

The better type of tethered goat (called in Greek *Peratiki*) is usually fawn and white, short-haired, with pendulous ears and roman nose. It may be described as of Nubian type. Reddish, or black-and-tan, coloured goats are less common, but the former usually show that they have Maltese blood. Black goats are least common and they are usually derived from the free-range type and are rough haired. The best of these goats are reputed to give up to 1 gallon of milk per day but 4 to 5 lb. is probably a fair average daily yield at their best.

Although, as stated above, the Maltese goat was probably first introduced many years ago, it was not until 1930 that the Agricultural Department imported a small consignment of twelve for improving the tethered goats, particularly in areas where free-range goats were excluded under the Goats Law. This law provides for the exclusion of free-range goats from villages that elect by ballot not to allow them to be kept. Tethered goats are excepted provided not more than four over one year old are kept by one householder. By 1945, 178 out of about 600 villages in the island had balloted in favour of exclusion.

In 1944 the Department imported from Palestine five kids of the Damascus breed. This breed is native to Syria but is increasing in numbers as a dairy breed in Palestine, and it was thought to be more

suitable for crossing with good dairy goats than the Maltese. The Damascus goat is larger than the Maltese, reddish or red and white with a pronounced roman nose, and very long pendulous ears. Both horned and hornless goats occur.

Up to 1946, therefore, the Maltese breed was regarded as the best breed for improving goats in Cyprus. Better management and selection of the best of the local tethered goats had received little sustained encouragement. But in that year attention was focused on the increasing need for better land utilization, and at a conference on 'Land Use' held in April 1946 the need for reducing the free-range goat and for increasing both the numbers and quality of tethered or dairy goats was referred to [4, 3].

An indication of the increased interest taken in goats is shown by the numbers and use made of male goats kept at stud under government control in different years (Table 2).

TABLE 2. *Maltese Goats at Stud, 1934–46*

Year	*Number of goats at stud*	*Average number of services per goat*
1934	18	30
1939	17	35
1946	29	68

Although some information on milk yields of the Maltese breed, particularly in comparison with the native free-range goat, has been obtained, there is less information on the yield of Damascus and Cyprus tethered goats, but there is a strong presumption, as will be shown in this paper, that these breeds are better than the Maltese. The possibility of importing European breeds, as had been done in Palestine, has also been considered and some idea of what dairy goats will give in comparison with British breeds is shown in Table 3. Furthermore, there is the question of the dairy goat *vis-à-vis* the dairy cow as an economical milk producer for conditions such as exist in Cyprus. This point is important for, in a peasant country, the keeping of goats to provide household requirements of milk and cheese presents far less of a problem both from

TABLE 3. *Comparative Yields of Different Breeds of Goats (in pounds)* [3]

Breed		*Total yield, lb.*	*Av. daily yield, lb.*
Maltese	Av. lactation yield in Cyprus (1935–42) [excluding milk suckled by kids] . . .	445	2
,,	Maximum yield (1938) . .	1,010	3
Damascus	Av. yield in Palestine (Acre, 1945–6)	1,100	3–4
,,	Maximum yield (1946) . .	2,000	6½
Anglo-Nubian	Good annual yield in U.K. .	1,800	6
Saanen .	Good annual yield in U.K. .	2,500	8–10

the financial and the practical point of view than does the keeping of cows. Thus, the question of developing a dairy type of goat suited to Cyprus conditions instead of a breed of cow such as the Kerry, has yet to be decided.

Breeding and Management at the Government Stock Farm

Although goat husbandry may be said to have started at the Government Stock Farm in 1930, when the Maltese goats referred to above were imported, it was not until 1935 that milk recording was begun [5], since when some experimental work to test different methods of management as well as to compare Maltese with native goats has been carried out.

The main policy of the Stock Farm up to 1945 was to breed the Maltese goats for distribution of both males and females to breeders in areas where tethered goats were kept. Occasionally males were sold to breeders of free-range goats. A number of male goats was always kept available for stud and the various Stud Centres were supplied from the Stock Farm. By 1945 there were only a few pure-bred Maltese goats and it was decided gradually to replace the Maltese by the Damascus, which had proved so successful under Palestinian conditions. A small number of local tethered goats was also acquired to compare them with the Damascus breed with a view to improving them by selection or by grading them up to the Damascus.

Management.—The Government Stock Farm contains a large area of rough grazing and acacia plantations. The goat-herd, numbering about 20 to 25 females and their progeny, was usually grazed over this area, generally with the sheep flock, and was fed only a limited amount of concentrates or vetch straw at night. Tethering was not practised as the size of the flock and the nature of the experimental work made it impracticable. This system, so far as the female stock was concerned, was finally given up in 1946, although special grazing had from time to time been provided for the best goats. In 1946 the female goats were kept in a flock by themselves, and were grazed only in paddocks or on rough land close to the farm, but outside the plantation area. Folding on lucerne or other forage crops was introduced and hand-feeding was increased. Each milking goat is now housed in a separate stall at night, whereas before 1946 the flock was simply kept in a yard with the ewes. The male goats were always kept separately to avoid indiscriminate breeding and were housed in a yard at night with the rams. Kidding occurred from October to May, November to January being the usual time. The kids were suckled for approximately 2 to 2½ months before being separated and the goats milked by hand. This arrangement was unavoidable if successful rearing was to be achieved, bottle-feeding of a large number of kids being impracticable. Milking was done twice a day after weaning was completed, and the kids were kept entirely separate from their mothers once they were weaned.

Milk Yields

The Maltese breed.—Except in the first year (1935) when the milk was measured, it has been weighed in grams once a week and the daily

yields converted into weekly yields. Since the kids were allowed to suckle for an average period of 60 days, the milk yields given below do not include the quantity taken by the kids. The 'lactation' yields obtained each year are for the actual amount of milk obtained by milking after the kids were separated. At various times an estimation of the amount of milk given during the suckling period has been made for selected goats of different breeds and these yields will be given separately. Table 4 gives the average yield of Maltese goats with full-time normal yields from 1935 to 1947.

TABLE 4. *Lactation and Daily Milk Yield of Maltese Goats at Athalassa 1935 to 1947*

Year	*Number of goats*	*Days milked*	*Lactation yield, lb.*	*Av. daily yield, lb.*	*Maximum lactation yield, lb.*
1934–5	11	184	452	2·45	855 in 275 days
1935–6	13	193	454	2·35	721 „ 228 „
1936–7	12	225	463	2·06	812 „ 294 „
1937–8	16	209	510	2·44	1,010 „ 273 „
1938–9	15	187	517	2·77	831 „ 244 „
1939–40	9	208	569	2·73	763 „ 215 „
1940–1	4	221	422	1·91	486 „ 221 „
1941–2	8	202	260	1·29	355 „ 279 „
1942–3	10	181	446	2·46	561 „ 196 „
1943–4	9	183	264	1·44	414 „ 218 „
1944–5	4	175	449	2·57	580 „ 218 „
1945–6	6	283	702	2·46	836 „ 300 „
1946–7	5	193	642	3·3	835 „ 203 „

The big drop in yield in 1941–2 and 1943–4 synchronizes with 2 years in which grazing was scarce (the winter of 1941 and spring of 1944) and during which period several changes in management occurred. Apart from these 2 years the average yield remained fairly steady between 450 and 550 lb. until 1945. In that year the system of management was changed, more grazing on forage crops and supplementary feeding was provided, with a consequent rise in yield. The highest yields obtained each year are an indication of the capabilities of the Maltese goat. The highest yield ever obtained was 1,010 lb. in 273 days in 1938 and this yield, corrected to include the milk obtained by the kid, was estimated to be 1,320 lb.—an average of 4 lb. per day [6].

The Damascus breed.—Damascus goats, which were introduced in 1944, have been too few to provide reliable data under Cyprus conditions, but the two goats, each recorded for two lactations, have given the following average yields:

TABLE 5. *Yield of Damascus Goats at Athalassa*

Year	*Days milked*	*Av. yield, lb.*	*Av. daily yield, lb.*
1946	233	719	3·10
1947	200	994	4·97

The maximum yield for these two goats was 1,182 lb. in 224 days, an average of 5 lb. per day, and one gave a maximum daily yield of 8·1 lb. in her second lactation. Furthermore, a cross-bred Damascus-Maltese goat gave, in her first lactation, 867 lb. of milk in 203 days.

Yield of Damascus goats in Palestine.—To give some idea of the capability of this breed under Mediterranean conditions, the yields obtained at the Government Stock Farm, Acre, Palestine, in 1944–6 are given. This information was kindly supplied by Mr. B. M. Cameron and Mr. G. K. Read [8].

TABLE 6. *Yield of Damascus Goats in Palestine*

Year	*No. goats recorded*	*Lactation period, days*	*Av. yield, lb.*	*Av. daily yield, lb.*	*Maximum yield, lb.*
1944	15	255	835½	3	1,278 in 297 days
1945	18	265	1,224	4½	1,709 in 282 days
1946	17	290	1,250	4	2,039 in 313 days

The maximum yield of 2,039 lb. in 313 days given by a goat in her third lactation compares favourably with yields of Anglo-Nubian goats in Britain. The average daily yield of this goat was 6½ lb. per day or just over 5 pints. These figures show that the Damascus breed under careful management (the Acre goats are almost entirely stall-fed) will give excellent yields of milk.

Cyprus tethered goats.—Data for this type are limited as only a few selected goats have been milk-recorded at the Stock Farm. As a breed of goat, however, there is wide variation in yield, depending on both breeding and management, but there are goats in the island which give from 7 to 10 lb. per day in the first 2 or 3 months after kidding. The following yields were obtained at the Stock Farm for three selected goats purchased in 1946:

TABLE 7. *Yield of Cyprus Tethered Goats at Athalassa*

Year	*Days milked*	*Av. milk yield, lb.*	*Av. daily yield, lb.*	*Maximum yield, lb.*
1946	200	734	3·67	928 in 234 days
1947	192	640	3·33	766 in 203 days

Lactation yields for this type of goat recorded in private ownership vary from 700 lb. to over 1,800 lb. [3], and with good management it can be claimed that they compare well with the Damascus breed.

Comparison of Maltese with local goats.—Mention was made above of the milking ability of the Maltese goat in comparison with native free-range and tethered goats. The Maltese goat has been compared with the free-range goat in two experiments carried out at the Government Stock Farm in 1938–9 [9, 10].

TABLE 8. *Comparison of Milk Yields of Maltese and Native Goats*

Breed	*Treatment*	*Total yield, lb.*	*Range, lb.*	*Av. daily yield, lb./day*
Native	Grazing only	264±18	168–327	1·5
Maltese	,,	345±22	227–470	1·8
Maltese	Sp. grazing+2 lb. concentrates	785±51	631–1,010	2·9

On free range alone the Maltese gave a 30 per cent. higher yield than the native and the difference in yield obtained by good management and better feeding with the Maltese was over 100 per cent. These figures are significantly correlated with each other and the experiment, which was repeated with rather better treatment in 1939, showed that though the Maltese responds well to good treatment it is not a heavy milker under conditions of free grazing only, and as Maule said, in summarizing these experiments, 'is not a great deal better than the hardy local goat' [11]. Though no direct comparison between the tethered goat and the Maltese has been made, the concensus of opinion, based partly on the appearance of tethered goats seen at agricultural shows and in private ownership, is that if well managed they are superior to the Maltese.

Experience since 1939 with Maltese and tethered goats at the Stock Farm has confirmed that even with good feeding the Maltese breed is unlikely to give spectacular yields, the figure of 785 lb. being the highest *average* yield obtained at the Stock Farm in the 12 years 1935–46.

To complete this review of the milk yields of the different breeds the foregoing records obtained at the Stock Farm (Tables 4, 5, 7, 8) have, in the absence of direct experimental comparison, been summarized in Table 9 to give an idea of the capabilities of the three dairy breeds.

TABLE 9. *Approximate Annual Yield of Dairy Goats at Athalassa.*

Breed	*Av. yield, lb.*	*Maximum yield obtained, lb.*
Maltese	450–785	1,010
Tethered	650–740	928
Damascus	720–990	1,182

Butter-fat.—During the period 1936–47 the butter-fat content of goats' milk was tested by the Gerber method regularly up to 1941, and again in 1946–7. Most but not all these tests were done on morning and evening samples separately, at 1- to 4-weekly intervals throughout the lactation. The mixed samples of milk of all goats varied somewhat, the lowest being 3·77 per cent. in 1937 and the highest 4·76 per cent. in 1946. In 1938–9 a comparison was made of the milk of Maltese, native, and tethered goats. The 1939 tests were made in the Government Chemist's laboratory and were done at approximately 4-weekly intervals from

April to August [9]. Tests were made at the Stock Farm, in 1936 for Maltese only, and in 1946–7 for Maltese, tethered, and Damascus goats. The results are summarized in Table 10.

TABLE 10. *Butter-fat Percentage for Different Breeds*

Breed	*Year*	*No. of goats*	*Butter-fat percentage*		
			a.m.	*p.m.*	*Average*
Maltese	1936	13	3·96	4·99	4·46
	1938	16	..	..	4·05
	1939	15	3·93	4·50	4·22
	1947	5	4·42	4·69	4·56
Native	1938	10	..	..	4·99
	1939	9	4·88	5·57	5·23
Tethered	1939	5	4·55	5·28	4·92
	1946	2	..	..	5·05
	1947	3	5·01	5·71	5·36
Damascus	1946	2	..	..	3·96
	1947	2	4·16	4·54	4·35

It will be seen from this summary that the native and tethered goats gave the richest milk. The highest individual tests in 1939 were: native 5·91, tethered 5·78, and Maltese 4·92 per cent. The Damascus goats had the lowest average butter-fat percentage in 1947.

The solids-not-fat content of goats' milk was examined in 1939. Maltese goats' milk contained an average of 8·7 per cent. S.N.F. and native goats' 9·1 per cent. The difference in S.N.F.-content between morning and evening milk was very slight. It is worthy of note that the native breed compares well with the Anglo-Nubian breed in contents of butter-fat and S.N.F. of the milk.

Influence of date of kidding on milk yield.—Goats normally kid in the spring and in Cyprus usually from February to April, although kids are born outside these months.

At the Stock Farm kidding synchronized with lambing (in the autumn, October to November) and occasionally a goat which kidded at that time would kid again in the summer, though this practice was not intended. No difficulty was experienced in getting the goats in-kid in the summer and, provided there was sufficient grazing or other forage in the autumn, it appeared to be advantageous to have early kidding, as the goats continued in milk rather longer.

Figures for 90 lactations of goats kidding in different months are given in Table 11. These lactations though uncorrected for age or other factors show a significant increase in the total yield of goats which kidded in the autumn instead of in the early spring. This increase is also correlated, significantly, with the longer milking period.

Length of lactation.—The normal length of lactation for Maltese goats is approximately 9 months. That is to say, they suckle their kids for

2 to 2½ months and are then milked for 6½ to 7 months or approximately 200 days (the average number of 'days milked' in Table 4 is 203). Lactations may, however, vary considerably, due to such factors as date of kidding, feeding, date of subsequent service, and disease. Lactations have ranged from 4 up to 12 months.

TABLE 11. *Influence of Date of Kidding on Milk Yield*

Month of kidding	*No. of lactations*	*Av. milk yield, lb.*	*Av. no. of days milked*	*Av. daily yield, lb.*
October–November .	44	533·5±35	230±10	2·32±0·17
January–February .	46	440 ±22	185±4	2·38±0·11
Difference . . .	..	+93·5	+46	−0·06

The following figures for the 1938–9 experiments show the varying length of lactation of Maltese goats due to management:

	Av. lactation period
Autumn kidding and good feeding . .	328 days
Spring kidding and good feeding . .	267 days
Spring kidding and poor feeding . .	230 days

Native goats tend to milk for shorter periods. This was shown in the 1938–9 experiments mentioned above in which the lactation period for native goats was 7½ to 8 months with a milking period of just under 6 months, or an average of 173 days. It is unusual for a goat to milk right on until she kids again. It is the practice for tethered goats to be dried off after they are in-kid so that they have a rest period of about 3 to 4 months.

Average number of kids born.—Records of the number and sexes of kids born which are available for some 300 kiddings during the years 1935–47 show that the average number of kids per birth was 1·85 and that 56 per cent. of all kids were male, 40 per cent. female, and 4 per cent. hermaphrodite. The last-named were usually killed at an early age. They tended to occur in some years more than others and not regularly.

Estimated total lactation yields.—Although the figures for milk yield obtained at the Government Stock Farm are based on test-weighings *after* kids have been weaned, a certain number of figures are available for total yield based either on test-weighings made during the suckling period by temporarily removing the kids, or on yields obtained when kids were removed (or died) at birth or in the first 2 or 3 weeks, or on estimations made from the daily yield. A few such yields for selected goats are given in Table 12.

These figures give some idea of the capabilities of native and dairy goats under good management. Yields of over 1,000 lb. were in fact unusual: the yield of 1,825 lb. for a tethered goat probably reflects particularly careful management and may well be an exceptional yield.

TABLE 12. *Total Lactation Yields of Selected Goats*

Breed and no. of goat		*Lactation*	*Days suckled +milked*	*Total lactation period*	*Estimated total yield, lb.*	*Av. daily yield, lb.*	*Source*
Maltese	No. 80	7th	56+273	329	1,320	4·0	Estimated from daily yield
,,	No. 85	6th	76+274	350	1,206	3·4	,, ,, ,,
,,	No. 121	5th	41+203	244	1,192	4·8	Calc. from test weighings
,,	No. 17	8th	63+250	300	836	2·8	,, ,, ,,
Native	No. 26	2nd	24+194	218	650	3·0	Kids weaned 24 days
,,	No. 32	2nd	0+208	208	464	2·2	,, ,, at birth
Tethered	No. 148	2nd	—	291	1,825	6·3	Calc. by the owner
,,	No. 148	4th	51+240	290	1,070	3·7	,, from test weighings
Damascus	No. 136	1st	81+230	291	924	3·2	,, ,, ,,
,,	No. 136	2nd	51+224	284	1,590	5·7	Estimated from daily yield

Future Development of Goat Husbandry in Cyprus

Experience gained during the past 12 years has shown that the Maltese is not outstanding as a *dairy* goat for improvement of the local tethered goats in Cyprus. On the other hand, experience in Palestine with the Damascus breed (and with the Saanen [8]) has led to the view that they are likely to prove more successful in Cyprus than the Maltese. The possibilities of improvement of dairy goats have been summarized by Maule [3] as follows:

> It is probable that considerable improvement could be obtained by grading up the existing type of tethered goats with breeds such as the Anglo-Nubian, Saanen, British Alpine, or Damascus. These breeds, with the possible exception of the Damascus, are much more prolific milk producers than the best local tethered goats. Good goats of the first three breeds will give from 2,000 to 4,000 lb. milk in a year or from 2 to 4 times as much as the best tethered goat now gives. Moreover, the Saanen and British Alpine breeds will milk under good management for nearly 2 years continuously if not mated.

Apart, therefore, from the question of what is to be done with the free-range goat, the improvement of dairy goats must, it seems, be achieved either by crossing them with more prolific milking breeds, such as the Saanen, Anglo-Nubian, and Damascus, or by careful selection of the best type of local tethered goat without using any outside breed. The Cyprus tethered goat is, it is true, a type rather than a breed, and therefore there is considerable variation both in appearance and in milking ability. Many of these tethered goats, however, could be graded up to the Damascus, a breed which is obviously suited to Mediterranean conditions. To do this it will be necessary to import and build up a nucleus of pure-bred Damascus goats, whose performance would have to be carefully tested. The importance of good management cannot be over-emphasized as individual goats will respond quickly to kindness and are susceptible to individual attention in everyday management. These are points which the improver is apt to overlook, for dairy-goat husbandry is, as yet, in its infancy in the Middle East. The work done in Palestine with Damascus goats indicates that higher yields than have so far been obtained in Cyprus may be expected.

There is undoubtedly a future for the development of goat husbandry

in Cyprus both to meet the changing needs of the people and to fit in with modern land-use requirements; and with proper guidance and encouragement increases in the yield of milk from dairy goats should be achieved.

Conclusions

The importance of dairy goats in Cyprus is now fully recognized, but the work carried out with the Maltese breed has not proved it to be ideal for improving the island's tethered goats which are increasing in numbers. Selected Maltese goats have given average yields of 785 lb. of milk per lactation under good management, but the normal average on the Government Stock Farm was from 450 to 500 lb. compared with about 300 lb. for native goats.

The Damascus breed, which has given average yields under stall-fed conditions in Palestine of over 1,200 lb., seems likely to replace the Maltese, although there are still very few of these goats in the island at present.

Very little work has as yet been done in the selection of the local tethered goat. These goats show very considerable variations depending on the care and management they receive as much as on their breeding, but the few tethered goats so far recorded have given satisfactory yields of milk, including one of 1,800 lb. The average butter-fat percentage for this type of goat is higher than for Maltese, being from 5 to 6 per cent.

The possibilities of importing Saanen goats are referred to, but the milk of this breed has a lower butter-fat content than the Damascus, a breed which is probably most likely to succeed in Cyprus. Considerable improvement by crossing is possible provided careful management is always ensured, but without careful management the tethered or dairy goat is not likely to be a great success.

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IRAQI LIVESTOCK

GRAHAME WILLIAMSON

WITH PLATES 1, 2, 3, 4

Introduction.—The information contained in this note was obtained during the first 3 months of 1948, by direct observation or from stock owners and attendants, colleagues, and others intimately associated with the subject. Unfortunately it generally had to come through the medium of an interpreter.

About 78 per cent. of the population of Iraq are agricultural, but only 3 million acres of land are cultivated. The nomads, who form a considerable proportion of the people, depend entirely upon animal products derived principally from sheep- and camel-raising. Livestock is also the chief interest of the semi-nomads who cultivate land in favourable years but revert to sheep-grazing when crops fail. The marsh Arabs in the south derive their living from buffaloes.

Except for relatively small quantities of green fodder grown around the towns and used by the dairymen, no crop is cultivated primarily for livestock. Most of the cereal straw is preserved in the form of *tibben* and, in the hills, a certain amount of tree leaves is stacked, but otherwise no conservation of fodder is practised. Dairymen's buffaloes and cows, a small proportion of the total, are hand-fed, but all other domestic animals for varying periods of the year are on a diet below maintenance level. The number therefore depends upon what can survive on the grazing available in the annual seasons of scarcity, that is if it has not been reduced more than ordinarily by disease.

To the usual difficulties of taking a census, associated with the suspicion of conservative countrymen, must be added those resulting from the nomadic habits of so many of the owners and their belief that accurate reckoning of possessions is both impious and unlucky. No records of individual, herd, or breed production are available, but the considered opinions of acknowledged authorities concerning it are inserted in the belief that they are a useful substitute.

The official figures of the livestock in 1947 are: sheep, 7,424,228; goats, 1,965,304; milch cows, 559,617; cattle over 6 months, 229,978; buffaloes, 132,501; horses, 194,038; donkeys, 432,484; camels, 306,566. The numbers of animals for which tax was paid in 1938 were: sheep, 5,523,000; goats, 2,223,500; camels, 82,400; buffaloes, 59,500.

Both as capital and revenue, sheep are much the most valuable of the livestock, and cattle, because of their number and despite the fact that they are neglected, are the next important in money value. The status of horses is very similar to what it is in the U.K. Their value for work on the land or as the producers of mules has been little impaired as yet by mechanization but it may decline rapidly as tractors become available. Their value for racing was severely checked when their import into India was banned, but as the Arab retains his pride in and love of

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the horse, its local commercial value is still high. For these reasons it is very difficult to estimate its true value to the country. The Arab horse has been so fully described that it is not referred to again in this note.

Sheep

Breeds.—All Iraqi sheep are fat-tailed. There are three chief breeds—the Arabi, Awasi, and Kuradi. Probably there are twice as many Awasi sheep as there are of the other breeds. The two most notable varieties of the Awasi are the Neahami and the Shafali. The Hamdanya strain of the Kuradi is marked by superior characteristics.

Arabi sheep [Plate 1 (*a*), (*b*)] are wanting in the best qualities of the European breeds. They are rather small and somewhat leggy. The rams have a fairly pronounced convexity of face and carry strong horns. The ewes are polled and have a short, pointed face. The ears are pendulous and of medium size: 1–3 per cent. of them are rudimentary, a character shared to a lesser extent by the other breeds. The udders are not well developed. The fleece, which comes well on to the head but stops clear of the shanks, is predominantly black. Some 30 per cent. carry only patches of colour. The wool is finer than that of the other breeds.

The *Awasi* [Plate 1 (*c*), (*d*)] is the heavy breed of Iraqi sheep. The head is big and rather coarse. The pronounced convexity of the face of the ram masks its length but balances the heavy horns. The ears are large and semi-pendulous. The fleece is stronger than that of the Arabi and the percentage of medullated fibres may be quite high.

The *Neahami* type [Plate 2 (*a*), (*b*)] is clearly distinctive although the name indicates a quality rather than a genetic variety. In every respect it is finer in conformation than the ordinary Awasi. The body is more substantially built: the limbs are shorter and more fleshy. The fineness and density of the fleece is a marked feature, as is also the deep-milking quality of the ewes. The fleece is generally white and the face black, but a reddish shade of varying intensity is common, and as it extends to the fleece it somewhat offsets the superior qualities. The variety approaches the European type in many respects, so much so that it raises the surmise that its qualities are due to the introduction at some time of Western blood. It is, however, held to have originated around Aleppo, and the Shammar tribe is reputed to possess the greatest number of the best specimens.

The type referred to as the *Shafali* probably owes more to environment than to heredity for its distinction. It is found on the cultivated land around Hai in the Kut liwa.[1] It differs from the ordinary Awasi only in its greater size and earlier maturity.

The *Kuradi* [Plate 2 (*c*), (*d*)] is a stocky, coarse-wooled hill sheep. Both sexes are polled. The face is black and, in many, the colour is carried on to the white wool on the breast and front of the shoulder. The face of the ewe is markedly long and straight. The ears are pendulous and blunt at their extremity. The true tail is remarkably long; it extends well beyond the fatty appendages. The wool is coarse but the staple is long. The percentage of medullated fibres is high.

[1] Liwa = an administrative district.

At Chalak, in Erbil liwa, there is found a type of sheep which to all appearances is of the plains variety but which some authorities consider a variety of the Kuradi breed. According to the owners, two related families, these sheep originated from a flock brought some 60 years ago from what is now Iran territory north of Erbil when the families migrated. The sheep are referred to locally as *Hamdanya* [Plate 3 (*a*), (*b*)]. Both sexes are polled, have large, black, fine heads with somewhat convex faces in the rams and slightly convex in the ewes. The ears are long and pendulous, and terminate in a curved point so characteristic of Indian Gir cattle. Some of the ewes have two skin appendages on the throat. The udders are well developed and the teats large, being up to 2 in. long. At the height of lactation a good ewe gives 3 litres of milk each day. They are prolific and mature early. They carry a heavy fleece of rather hairy-handling wool. They cannot stand extremes of atmospheric temperature.

Husbandry.—Most of the sheep are owned by nomadic graziers or by the richer cultivators, but the owners of arable land and even city merchants possess considerable numbers. The former live by, for, and with their flocks. They move out each spring and winter along the depressions in the desert as the grass becomes available, and when the wells dry up they move back to the fringes of the irrigated land and to the fallows along the canals and rivers. Those on the hills migrate down to or up from the plains as weather dictates. The mainstay of the stock of the latter class of owner is on the arable where feed from the stubble, weeds, and fortuitous grazing on common ground or nearby desert, and the rich grazing of the winter wheat, afford keep throughout somewhat more than half the year: for the rest of the time their flocks are sent, under the charge of a hired shepherd, to spring and early summer grazing in the desert.

It is customary for the sheep-owner to pay in kind or, sometimes, in cash for the privilege of maintaining his stock on arable land other than his own. The value of the dung is doubtless taken into consideration, but, invariably, the ultimate debt lies with the shepherd. On occasions high prices are paid for spring grazing on cereal crops.

The distance the grazier travels depends somewhat upon whether the year's rains are good or bad. In any case they are relatively not great, but men of the Dulain and Muntifique tribes may traverse some hundreds of miles in the aggregate. The distance covered each day in the desert when the grazing is fairly good is 6 to 8 km. When making for any particular place, 16 km. a day is considered a fair rate of progress but, when pressed, shepherds have been known to take their flock as much as 35 km. in 24 hours.

The direction and extent of the seasonal movement of sheep-owning tribes is indicated on the sketch map on p. 51.

The terraine covered varies very much in character. In the south, east and south of the marshes, the flocks penetrate well into the desert and are brought to the comparatively expensive feed on the irrigated land only when the grass dries up and disappears. The breed of sheep found here is the Arabi.

To the east of the Tigris, summer food is available along the foothills of the frontier, and the desert grazing between it and the winter feed on the edges of the marshes and along the river-bank is adequate in the spring and autumn. Before the demarcation of the border by the international commission, the shepherds, even from the mountains well inside the present-day Iran, brought their sheep far down on to the plains during winter, and the Iraqi shepherds, in turn, penetrated well into

IRAQ.—To show direction of movement of chief sheep-owning tribes.

Iran in summer. On the boundary being fixed the sheep-owners had to decide upon which side of it they would be, and the majority chose the one offering the best all-the-year-round grazing. The result is that the number of sheep now found in the Amara liwa, for instance, is much less than it was and the stamp of sheep is smaller. Some owners consider them to be of the Arabi type, whilst others claim theirs to be Awasi.

Farther north towards and in the centre of the country where the sheep are bred and fattened on the rich grazing afforded by the winter cereal crops and the summer stubble, the true Awasi is found. That is, from Kut and the lower Tigris marshes, up between the rivers through Hai, Daghghari, Samawa, Hilla, and the Jazira west of the Tigris to the

region of Mosul. East of the Tigris, north of the lower Diyala and Baghdad, the pastoral region stretching intermittently into the Mosul and Erbil liwas, as well as that lying between the middle Diyala and the Jabal Hamrin and extending north of the Little Zab is good enough to support the Awasi type of sheep.

Along the foothills of Kirkuk, Erbil, and Mosul, the Kuradi breed is located.

Calculated per head of sheep, the area for grazing appears to be immense, but actually it is quite limited by the scarcity of wells and by large barren tracts.

The fertile areas are well known and are grazed heavily: endozoal parasitism is therefore common. The increase of irrigation along with the tendency to overstock, and the periodic crowding on the fringes of the marshes and pools are responsible for heavy losses from distomiasis.

Practically nowhere is strict attention given to the maintenance of pure strains or breeds. Although it is possible to distinguish the three main breeds, there is no clear demarcation between them. The nomadic shepherd, knowing what periodic hardships his flock must withstand, will not use a ram which he knows to have been reared under easy conditions and which he therefore believes to be unable to travel, or to be liable to get stock which would be unable to exist on scanty living. Nevertheless, the rams are frequently selected merely on the whim of the shepherd, although more often the son of a deep-milking ewe and a sire of proved fertility is chosen, provided he is well developed and active. Within the last decade or two, the export wool trade has taught the intelligent owner the value of a white fleece, and the shepherd has observed the influence that a white-fleeced ram has on it, but among the nomads, both in the north and south, a black ram may still often be seen with a flock of white ewes. On at least two occasions, illiterate shepherds have commented correctly on the genetic significance of the white ram. Around the baling stations at Samawa and Baghdad, no coloured breeding rams were seen, and the completeness of the transformation was also noted around Amara, a former baling station.

Only rarely is the ancestry of any individual known beyond one or, at most, two generations. The rams run with the ewes throughout the year, but there are two main lambing seasons corresponding to the beginning and the end of the winter—October and November, and February to the end of May.

Good ewes, on good feed, lamb every 18 months, on the average. Not more than 1–2 per cent. of births are multiple.

Various authorities reckon that, because of famine and disease, the average lamb crop is from 40 to 60 per cent. After paying all dues from his flock, if 35 lambs per 100 ewes are reared to maturity each year the position is considered normal.

Products.—Of the three chief products, *deehin*, or clarified butter, is generally considered to be the most important. It is the country's chief source of edible fat.

To sheikhs and similar men of standing, mutton is the primary

product. To all, wool is considered of least importance although, in the aggregate, even in its present undeveloped state, its monetary value is higher than that of either of the other two products.

The *deehin* is made as follows: the ewes are milked by the women as they are folded each evening. The day's milk is curded, the cream separated and churned in a skin. The butter is then removed and when sufficient has been collected it is clarified by boiling. During the process the water is evaporated and the curd solidified so that it can be removed from the fat, as are the other solids separated by skimming. The *deehin* is stored in a skin until it is convenient to trade it. The dealer, without blending or processing it, merely packs it in sealed earthenware jars or in tins. In the former it is said to remain in good condition for at least a year: in the north it is acceptable as having undergone little deterioration up to two years. The amount derived from each lambing ewe is reckoned to be 1 kg. from those of the Arabi breed, 1–1·5 kg. from the average Awasi, and up to as much as 3 kg. from the superior northern Awasi. When *deehin* is made by the Kurdi owner, 1·25 kg. per season is obtained on the average from each ewe.

Ordinarily not much *meat* is eaten, but the entertainment of guests demands as lavish a supply as can be afforded, so that from year's end to year's end the great majority of surplus stock is used for home consumption. There is, however, an extensive export trade in live sheep from the northern liwas, chiefly from Mosul, to Syria and Palestine in normal times. The northern breeds are credited with supplying the best mutton, a feature due probably to the food-supply rather than to any genetic character. Six kg. of meat, excluding offal, can be obtained from the carcass of a well-fed lamb of 6 months, and anything from 16 to 20 from a full-grown sheep. Seven kg. of meat were obtained from the carcass of a 4-month-old Awasi lamb which, apart from good flock-feed, had no forcing treatment.

Iraqi *wool* is mostly of the carpet type; the average qualities are well known to the trade. The best is obtained from Diwanyah, Samawa, and south of Hilla. Quite 80 per cent. of the Arabi wool, 20 per cent. of the Awasi, and 5–7 per cent. of the Kuradi is coloured. There is greater variation in quality than usual not only between breeds or between flocks but within each flock. Individual fleeces of comparatively fine wool are found in most flocks. Nothing finer than English 36s is spun from Iraqi wool as now sorted locally. The finer varieties are nicely crimped. The measurements of the fibres of superior fleeces, given on p. 54, indicate the advantage that might accrue from controlled breeding.

The finest wool is produced by the Arabi sheep; that of the Kuradi is distinctly the coarsest. The crop is bought from the sheep-owners by the fleece but thereafter it is dealt with by weight. This may account for the common practice of leaving the breast and the front of the shoulder unshorn. Shearing takes place in April and May. Whenever possible the wool is washed on the sheep but otherwise the fleeces are sent to such collecting centres as Baghdad, Diwanyah, and Mosul, where they are rough-scoured in the river without solvent. After a certain

amount of deburring the fleeces are skirted and classed for baling. Practically all the white wool is now exported: the rest is used to meet the local demand for natural coloured wool.

TABLE 1. *Body-size and Wool Measurements of Iraqi Sheep*

Breed	Average height at withers of typical specimens, in cm.		Measurements of selected specimens of finer wool				Average yield per annum kg.
	Ewes	Rams	Source	Mean length of fibres, cm.	Mean diameter of fibres, microns	Hair %	
Arabi	..	..	..	..	..	..	1·0
,,	..	..	Ewe, 4 yrs.	14·296	32·593	5·00	..
,,	..	..	,, 4 yrs.	..	27·806	..	..
,,	..	..	,, 1 yr.	..	32·527	0·67	..
,,	..	..	,, 3 yrs.	..	28·580	3·33	..
Awasi	62 (61–8)	76 (70–81)	12♀♀ 12♂♂	..	..	..	1–1·5
,,*	..	..	Ram, 2 yrs.	20·450	36·000	10·64	..
,,	..	..	,, 4 yrs.	..	33·793	1·67	..
,,	..	..	Ewe, 2 yrs.	18·049	26·533	nil	..
Neahami*	..	..	Ram, 2 yrs.	13·860	34·000	,,	..
Kuradi	58	71	11♀♀ 10♂♂	25·000	..	..	2·0
Hamdanya	76	85	1♀ 1♂	..	..	..	2–2·5
,,	..	..	Ewe, 2 yrs.	18·790	35·227	0·67	..

* Kindly measured by Dr. B. K. Vaidya of the University of Bombay.

Buffaloes

Although both their total capital value and the value of their products may be less than those of the cattle when expressed as cash, yet buffaloes are probably of more economic importance to the country. It is from them and not from the cattle that a great proportion of the country's milk-supply is obtained. They are virtually the entire means of support of the true marsh Arabs and are one of the chief sources of income of their immediate neighbours as well as those of their kin who have migrated to the urban areas as dairymen. It has been recorded that one-third of the buffaloes are in Amara liwa and one-half in the liwas of Basra, Muntifique, and Diwaniyah. The main breeding centres and sources of supply are the marsh lands of Amara and Diwaniyah, but the buffaloes of Hilla include some of the best milkers in the country.

Description [Plate 3 (*c*), (*d*), Plate 4, (*a*)].—There is no reason to believe that there is more than one breed. The differences in appearance between the buffaloes found in the marshes and those in other parts of the country are probably due to different feeding and management. The former subsist entirely upon coarse water-grasses or reed-like plants, whilst the latter are fed liberally, sometimes extravagantly, when in milk in an urban area, and at other times get some concentrates when their adequate fodder-supply lacks quality. Minor differences, such as the shape of the horns or white patches of hair, may be noted which may distinguish the stock of one district from another, but more

often these differences are the characteristics of families in the locality and may be seen in several widely separated districts. Thus at Samawa a white blaze, broad at the poll and narrowing to its termination two-thirds of the way down the face, along with white shanks on all four legs is very common, but these marks may be often seen in families elsewhere although the markings may not be of such a standard pattern. The horns of the marsh buffalo are of the open-sickle shape; at Hilla and north Diwaniyah many are much more acutely curved, and in Basra whole herds may be seen with horns sloping half-way along the neck and curved upwards in the last quarter only. The marsh buffalo is reputed to stand higher at the withers than others, but no confirmation of this could be obtained. Certain it is that the marsh buffalo, being in rough condition, looks taller and more leggy. Measurements are difficult to take: the average height at the withers of 19 cows typical of those in different parts of the country was 143 cm. (137–50) and the length 153 cm. (147–63 from point of shoulder to pin-bone). The girth was very variable, being from 182 to 218 cm. with an average of 209 cm.

All Iraqi buffaloes, wherever kept and however fed, have a coarse robustness such as is never seen, for instance, in the Indian buffalo, but, on the other hand, they lack the fine quality of skin, the sleekness, and the solid, substantial outline of the better Indian breeds. The head, even in good cows, is coarse and is carried somewhat high on a relatively long but thick neck. The face is straight or slightly dished. The withers are high and the croup and haunch bones prominent. The body is rather elongated and has little of the squareness associated with a high-producing buffalo. The legs, in relation to the size of the body, are long but not coarse. The croup is inclined to droop. The tail falls to a little below the hocks. The switch is small. The udder is seldom big or fleshy, but is carried well back and is provided with good-sized, well-placed teats. The skin of the udder is surprisingly fine. The colour of the great majority is a whole slatey black, but many are grey and some have a reddish or dun hue at the extremities. White on the head, legs, and tail is also very common and some animals carry large patches of white on the body. Now and then individuals may be seen which might correctly be described as being white with black patches. Many, but not all, animals with white points are wall-eyed.

Production.—During and after the First World War, large numbers of Indian buffaloes were imported by the British army to Basra, where they did well when fed adequately on concentrates. Later the military dairies closed and the stock, bought by local buffalo-keepers, was fed and managed on the same lines as the country-bred animals. Under these conditions they and their progeny quickly degenerated and died out, and now no trace of them can be found.

The milk yield from good cows at the height of their lactation is about 3 gal. each day. At a well-run commercial dairy in the north, where fairly accurate observations were made of the milk yield, it was reckoned that in a total lactation 350–400 gal. were obtained from each cow. In another fairly well-managed dairy in Baghdad it was noted that 31

buffaloes yielded an average of 12 l. each on the day of observation. The Hamar Lake buffaloes, in spite of getting no concentrates, yield up to 13 l. each day at the height of lactation.

The marsh cows are milked by the men once a day when they return, of their own accord, from their grazing, generally in water several feet deep. Elsewhere two milkings is the rule—in the very early morning and again about midday. In the marshes *deehin* is the chief commercial product, but in other localities where daily sales are possible the cream is sold fresh. The marsh cows milk for only 4 or 5 months or, as some put it, 'three months after being served'. If the feed remains good, however, and the cow is not bulled, she will remain in milk up to a year or even 2 years. In dairies where concentrates are fed and milk secretion stimulated, the average lactation is 8 months. It is estimated that two-thirds of the cows calve each year and that, on the average, each produces 5 l. of milk daily in a lactation of 135 days. Twenty per cent. of the bull calves and 10 per cent. of the heifer calves die.

Husbandry.—The marsh buffalo is entirely maintained on roughage, the great bulk of the food being *marram* (*Panicum repens*), *cholan* (any rush or reed-like plant but usually *Cyperus scirpus*), and *qasab* (*Phragmites communis*, as well as *Erianthus* and *Saccharam*). On the edge of the marshes where a market for fresh milk exists, large quantities of bran, mostly rice-bran, are fed. In the urban areas the feeding is very liberal. In Karbala, for instance, the owner of the bull depicted in Plate 4 (*a*) fed to each of his cows as much as they would eat of a mixture of equal parts of *tibben* and *hashish* (green wheat, legumes, and grass) and 16 kg. of a mixture of rice, sesame, or cotton-cake, and wheat-bran, 2 parts of each with 3 parts linseed. At Hilla an owner of another herd in good condition whose cows were yielding an average of 8·2 l. per day, gave each one as much as she would eat of *tibben* as well as 50 kg. of *hashish*, 8 kg. of barley-feed, 2 kg. of cotton-seed, and 4 kg. of rice-bran. Instances of even more liberal feeding in other town herds were noted. In Mosul an average feed of concentrates is 3 kg. cotton-seed and 6 kg. barley-feed each day to cows yielding not more than 4–5 l. of milk.

Breeding.—The marsh Arab selects his bull with some care. He chooses the son of a deep-milking, long-lived cow. Dairymen, on the other hand, who have little interest in rearing stock, use bulls just as their fancy guides. One bull is considered sufficient for 60–100 cows, and the fewest number possible is maintained both because of the expense and their pugnacity. For these reasons a bull is seldom retained for more than a year, once he has reached puberty: it is at this stage that he becomes difficult and fetches the maximum price from the butcher or dealer.

A heifer, if well fed, first calves as a 3-year-old. On scanty, hard living she may be even 5 or 6 years of age before she takes the bull. The average age of first calving is 4 years. A cow is reckoned not to degenerate until she is 12 years old. Many fail to breed before they are that age and are discarded.

The term 'urban dairy' as used here does not denote an establishment in any way resembling a Western dairy. The Iraqi dairy herd, and

especially the urban one, is kept under the foulest sanitary conditions. The milk is distributed generally by the crudest methods of handling, but it is boiled by the consumer.

Cattle

There are no large herds of cattle in the country, with the exception of a couple of private dairy herds in Baghdad and the herd at the government dairy farm, where the sale of milk and not the breeding of stock is the first consideration. In the northern liwas other herds of 100–200 head belonging to dealers may be seen. They consist of animals which have been collected for export or for sale to butchers when the market is favourable.

Husbandry.—Breeding is entirely haphazard and no breeding herd of any consequence exists. The cattle, composed almost entirely of cows and young stock, are owned in small numbers by the fellahin in the riverine areas and by householders or by small dairymen in the towns. The best milkers, and practically the only ones to receive adequate nourishment and attention, except those of the three herds already mentioned and some owned by wealthy families, belong to the Jewish milkmen in Baghdad and Basra. These are maintained in very cramped and as a rule in grossly insanitary yards which front the family living-quarters, the whole property being strictly enclosed by a high wall and generally situated in the heart of the city. In these quarters, often shared with other livestock, the whole business of the dairy takes place. Such environment is not characteristic of the Jews alone.

The same or worse conditions prevail in Mosul, Karbala, Amara, and other towns where the milkmen are not Jews, the only noticeable difference being the inferiority of the stock and the inadequacy of diet. Fellahin's cattle fend for themselves, picking up their living as best they can from the waste products of the crops and from such grazing as can be gleaned from fallows, bunds, and waste ground.

Breeds.—Nearly all the cattle are little better than scrub and it would be hard to say that they constitute any particular breed—they differ so much in conformation and capabilities and resemble each other only in their state of neglect. In certain localities, however, quite definite types exist and the following are considered to have characteristics sufficiently well defined to make them recognizable as breeds: 1. Jenoubi—from the south; 2. Dishti—Persian type; and 3. Restagi—Hilla cattle.

The *Jenoubi* [Plate 4 (*c*)] is considered to be much the best of the local types. In appearance and in details of conformation the best specimens so closely resemble the Indian Sindi that they might be mistaken for them. The purest are said to be found at Fao. A good one measured 116 cm. at the withers, 105 cm. from the point of the shoulder to the pin-bone, and had a girth of 157 cm. The average of four typical specimens whose breeding for two generations was known was: height, 113 cm.; length, 120 cm.; girth, 161 cm. In colour they are golden to bright bay and show no white. The best cows exhibit all the characters of good dairy cattle. The hump and dewlap are quite prominent but not big. The legs are short and the bone fine. The best are reputed to give up

to 15 l. at the height of lactation if well fed but the average is probably not much more than one-third of that amount.

The *Dishti* are much smaller animals. A typical one measured 99 cm. high, 105 cm. long, and had a girth of 133 cm. The hump and the dewlap are small and the udder is not well developed. The colour is most commonly a light tan to cream or golden. When well fed they give appreciably more milk than the scrub, but a typical one, at the height of lactation, was found to be giving only 2 l. a day, besides a similar amount reckoned to have been suckled by her calf.

The *Restagi* [Plate 4 (*b*)] is found in greatest purity in the neighbourhood of Hilla. It is considerably bigger than either of the two just described. A typical cow was found to be 127 cm. high and 138 cm. long, and had a girth of 153 cm. The prevailing colour is a very light dun and there may be some white markings. In general outline the cows are somewhat coarse and leggy, but the udder is wonderfully well developed and the skin fine and silky. The cows have a very small hump and little dewlap.

In addition to these three breeds, two other types deserve mention, the small black-and-dun hill cattle located in the north which, except that they are humpless, are of the type found throughout the highlands of southern Asia; and the cattle which bear more or less blood of the Western breeds. The former, like the nondescript cows of the plains, give just enough milk to rear their calves but, when brought on to good grazing, they fatten quickly and are used for beef. The latter, i.e., the cross-breds, are so superior that almost any cow with foreign blood commands a premium. Many of the European breeds such as Friesian, Ayrshire, and Jerseys have been introduced from time to time, but there has been no continuity of breeding policy either in any particular herd or in the country in general. European crosses do well in and north of Baghdad. It is reckoned that one-third of the cows in the country calve each year, that 15 per cent. of the calves die, and that the amount of milk obtained for human consumption from the cows, although it may be appreciable from a few thousand, is, on the average, negligible.

Goats

Most of the goats are in the northern liwas, but a feature of Kut is the flocks of small black goats of a breed found widespread throughout the country and which make up the majority of the goat population. In the northern hills and the plains of Mosul, Erbil, and Kirkuk, the black goat [Plate 4 (*d*)] is largely replaced by the larger Kurdish or long-haired hill goat. They are light in colour or white. The hair has little purl but may be 24 cm. long. In addition to these, a certain number of goats closely resembling an inferior type of Angora are found in the northern liwas.

The goats are usually bred and reared along with the sheep and at least a few of them will be found at the head of each flock. As producers of meat and milk they are, of course, inferior to sheep, but from each of the small black goats is obtained about half a kilo of hair with a staple

a. Aged Arabi ram.

b. Young Arabi ewe. Mean diameter of shoulder wool-fibre, 27·866 microns.

c. Four-year-old Awasi ram. Height at withers, 73·5 cm. Mean diameter of shoulder wool-fibre, 33·793 microns.

d. Two-year-old Awasi ewe. Height at withers, 61 cm.

a. Two-year-old Neahami ram. Height at withers, 77 cm. Mean diameter of shoulder wool-fibres, 34 microns.

b. Young Neahami ewe.

c. Two-year-old Kuradi ewe. Height at withers, 68 cm. Mean diameter of shoulder wool-fibres, 35·227 microns.

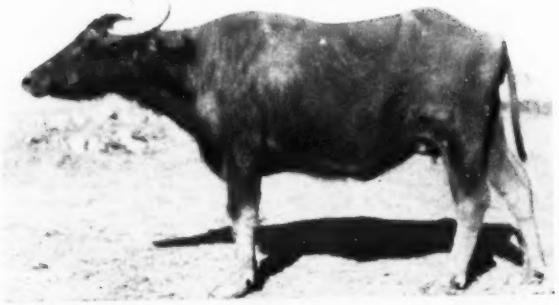
d. Two-year-old Kuradi ram. Height at withers, 77 cm.

c. Two-year-old Kuradi ewe. Height at withers, 68 cm. Mean diameter of shoulder wool-fibres, 35·227 microns.

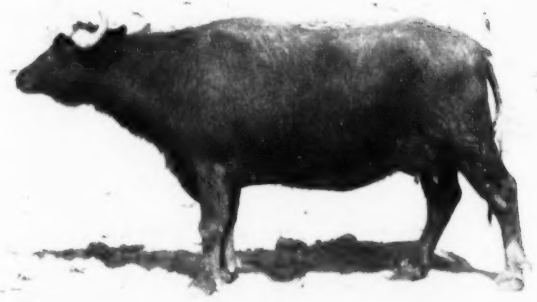
d. Two-year-old Kuradi ram. Height at withers, 77 cm.

a. Four-year-old Hamdanya ram. Height at withers, 84·5 cm.

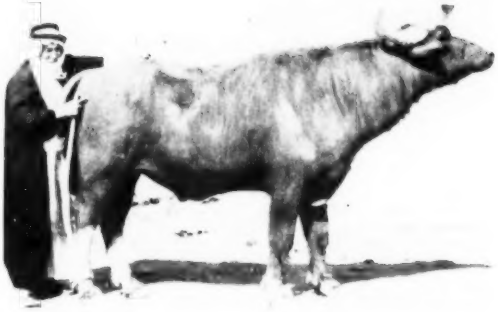
b. Head of Hamdanya ewe showing skin appendages on throat.



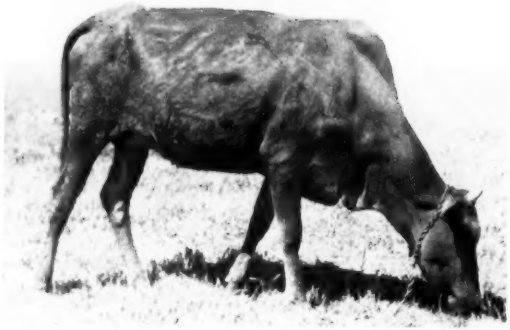
c. Marsh buffalo heifer.



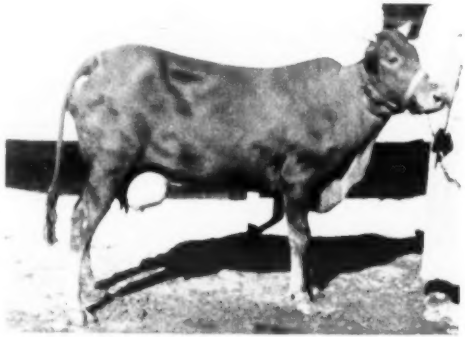
d. Typical dairyman's buffalo.



a. Buffalo bull. Height at withers, 150 cm. Length from point of shoulder to pin-bone, 166 cm. Girth, 240 cm.



b. Restagi cow.



c. Jenoubi cow.

d. The common black Iraqi goat.

length of 10 to 13 cm. from which is spun the waterproof matting used by the nomads for making their tents. No mohair is produced in the country. The goats are credited with having depleted the forests on the foothills and with causing grave damage to the only wood-supply grown in Iraq.

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THE POTATO-ROOT EELWORM (*HETERODERA ROSTOCHIENSIS* WOLL.) IN THE UNITED KINGDOM

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THE occurrence of the eelworm on the roots of potatoes in the United Kingdom was first recorded by Massee in Scotland in 1913, but at that time the organism was not associated with pathological symptoms. In 1913 Zimmermann [1] first recognized that eelworm attack could interfere seriously with potato cultivation and described its incidence in the Mecklenburg area. It was some years later before similar attacks were found to occur in the U.K. The first definite record of the potato eelworm as a serious pest of potatoes in the U.K. was made in 1916 by Taylor, who found this eelworm associated with the condition which later came to be known as 'potato sickness' in gardens near Leeds and at Wetherby. Field attacks, however, were not discovered in Yorkshire until 1923, although there is some evidence that they did occur much earlier. Strachan and Taylor [2] cite a potato trouble in the South Cave area of the East Riding of Yorkshire, known locally as 'Dab', which dated back to 1904. Later investigation indicated that this condition was produced by potato eelworm. The first recorded heavy attack in the field, resulting in almost total crop failure, was at Gamlingay, Cambridgeshire, in 1919.

There is no doubt now that the intensive potato production which was necessary during the 1914–18 war and in subsequent years resulted in the firm establishment of the eelworm in the main potato-growing districts. By 1923 further serious field-scale attacks were known to have occurred in Cambridgeshire, Lincolnshire, and Yorkshire, and from that time onward infestation spread to all parts of the country where potato-growing is intensive. Restrictions of potato acreages were imposed in the 1930s in some districts where eelworm infestation was heavy, but on the outbreak of war in 1939 the need of more potatoes necessitated the removal of restrictions and resulted in a big acreage increase in heavily infested areas, with consequent further establishment of the eelworm. It is now common in all the main potato-growing areas in England, in allotments in all parts of England and Wales, and in the southern half of Scotland, where well-defined centres of infestation include seed-producing areas, a factor of some significance.

Areas affected.—In Scotland the occurrence of potato eelworm appears to be confined mainly to the southern counties: in parts of Ayrshire, Kirkcudbrightshire, E. Lothian, Ross-shire, and Dunbartonshire, seed-producing areas being affected as well as districts where the growing of potatoes for the early market is an important industry.

The chief potato-growing counties of England show very large areas where eelworm infestation is common, the main ones including SW. Lancashire, SE. Yorkshire, extensive tracts in Lincolnshire (Holland and Kesteven Divisions), Soke of Peterborough, Isle of Ely, parts of

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Huntingdonshire, Cambridgeshire, and Bedfordshire. Relatively small infested areas occur on the Durham coast, in Nottinghamshire, Staffordshire, Worcestershire, Norfolk, Isle of Wight, Dorset, Devonshire, and Cornwall.

Wales has no extensive area where eelworm infestation is serious, although, in common with England and Scotland, infestations in gardens and allotments are often extremely severe.

The proportion of infested fields in the main potato-growing parts of England is high. Intensive surveys for advisory purposes have been carried out in some of the affected counties for a period of years and these have shown the proportion of arable land in these areas with some degree of eelworm infestation to be of the order of 60–75 per cent. The following analysis of soils sampled in SE. Yorkshire and SW. Lancashire for the 1948 crop may be taken as typical of other infested localities.

TABLE 1. *Field Survey of Certain Infested Areas*

No. of fields sampled	*Total acreage*	*Fields infested in some degree*	*Field with 4 or more viable cysts per 10 gm. of soil*
1,128	7,818	711 (63 per cent.)	213 (18·8 per cent.)

The eelworm position in Northern Ireland is a very happy one, with a remarkable degree of freedom from the pest. The writer is indebted to Mr. R. Chamberlain, Queen's University, Belfast, for the following information. The eelworm position is greatly influenced by two factors: (1) importation of seed potatoes into Northern Ireland is permitted only under licence; and (2) in the normal rotation practised it is exceptional for potatoes to be grown more often than once in 7 or 8 years. A very extensive survey to assess amount and extent of infestation has been in progress since 1945, particularly in seed-producing areas and localized districts where more intensive potato-growing is practised. This has revealed that of 100,000 acres sampled less than 500 acres (0·5 per cent. of acreage sampled) showed infestation by the eelworm; other parts of the country not yet sampled are believed to have an even lower incidence.

Under the terms of the Potato-Root Eelworm (Northern Ireland) Order 1945 growers of potatoes or tomatoes are compelled to notify the Ministry of Agriculture if the presence of eelworm is known or suspected. Where its presence is confirmed the Ministry prohibits the growing of potatoes or tomatoes on the infected land; also prohibited are the removal of soil from sick land and the removal of vegetables, weeds, or plants to the roots of which any soil adheres. Steam sterilization or re-soiling under Ministry supervision is compulsory in the case of glass-house infestation. The raising of seed potatoes is regulated to prevent the distribution of eelworm cysts with seed. No potato crop is considered for any form of seed-potato certificate unless grown on land with a 'wide' rotation, one in which potatoes are excluded for a prescribed number of years. A stock-seed certificate is issued only if the crop has been grown on land which has been tested and found to be free from potato-eelworm

cysts. The normal growing practice involving lengthy rotations together with the precautionary measures outlined should go far to secure for farms in Northern Ireland continued immunity from serious trouble.

Symptoms of attack on potatoes.—Franklin [3] has shown that young eelworms are induced to hatch and move to potatoes within 3 days after planting out. A plant growing in infested soil is handicapped, therefore, from the start, the first symptom of attack being that sprouts are delayed in coming through. As the attack continues and develops, growth remains backward and the plant poor and stunted, with weak, spindly stems. Paleness of foliage is characteristic, and many leaves show browning symptoms not dissimilar to those due to lack of potash.

More advanced symptoms appear on the lower leaves, the young upper leaves being the last to show the effect of the attack. Progressive wilting and falling off of the lower leaves as the effect of the attack develops results in the lower part of the stem becoming bare, with tufted leaves remaining at the top. Free-flowering varieties of potatoes show few or no flowers in infested areas. Heavily infested plants show, if lifted, a greatly reduced root-system with many decayed roots, and the tubers formed are small and reduced in number. Such plants if examined from midsummer onwards show eelworm cysts upon the roots. The cysts are creamy-white at first but as the season advances they become brown as the cyst coat becomes thickened and hardened. They lose their firm attachment to the roots and fall off into the soil, where they remain and give rise to infestation of a subsequent potato crop.

The death of plant-rootlets following eelworm invasion and the entry of fungus organisms reduces the capacity of the plant to take up water and plant nutrients, the plant, therefore, ultimately dying of drought and malnutrition. Symptoms of wilting of the leaves during hot weather indicate that the plant is unable to take up moisture as quickly as it is lost by transpiration. This symptom is more pronounced on tomatoes than on potatoes.

Where eelworm infestation is light the plant may be able to produce new rootlets at a greater rate than the older ones that are killed by the parasite, and the plant may show little evidence of attack, although growth may be delayed and the crop reduced to some extent. Where infestation is heavy, however, the plant is unable to produce new rootlets fast enough to keep pace with those killed. When this occurs the plant becomes exhausted and dies.

Attack on tomatoes.—Although the potato eelworm attacks only potatoes among agricultural crops, tomatoes are also liable to infestation. Morgan [4] first recorded it as a weak parasite on tomatoes, but later investigations in Yorkshire by Johnson and Thompson [5] showed potatoes and tomatoes to be equally susceptible. The earliest attack on tomatoes was noted in Yorkshire by Taylor and Johnson in 1928, but other cases soon occurred, and at the present time infestation on over 200 holdings in the county has been recorded. Attacks are now becoming increasingly common in Lancashire and in other parts of the country. In Yorkshire the main potato- and tomato-growing areas coincide; many tomato-houses, particularly those of Dutch type, were erected from

1930 onwards on 'potato-sick' land, and direct infestation followed. The eelworm was also dispersed by the sale of infested seedlings before the danger was realized.

The effect of attack on tomatoes is similar to that on potatoes. At first infestation usually occurs in patches, which later enlarge with succeeding crops, and as tomatoes are normally grown in the same soil each year serious trouble soon develops. Seedlings planted in heavily infested soil make good progress at first, but within 3 weeks begin to show signs of attack. Growth becomes retarded and severe flagging occurs, especially in hot weather. The foliage turns pale and later yellow, the roots reveal severe rotting, and creamy-white or brown cysts show upon the roots, often associated with small nodular swellings. Bad blossom-setting follows as a result of malnutrition due to root-injury, and the final crop of fruit is small in size, with a yield which may be as low as half a pound per plant.

Tomato plants that are heavily attacked can often be kept going by paying particular attention to watering, particularly in hot weather, and by mulching the plants with clean soil or with a high-grade peat. From July onwards there is some recovery, and it is often possible to get fruit from top trusses even where the bottom trusses have failed because of eelworm attack.

Other factors involved in 'potato sickness'.—Crop failures are frequently attributed to eelworm where this parasite may be only one of several adverse factors, all of which can result in weak growth and so render the crop more liable to serious eelworm injury. During the war, when transport difficulties often resulted in delays and undue exposure of the seed potatoes, 'chilled' seed was frequently planted. The writer has examined many such cases where at first sight symptoms were present that appeared similar to those caused by eelworm attack. Growth was slow and there was general lack of vigour; such faulty growth was, however, generally uniform throughout the crop, whereas eelworm attack is usually characterized by patchiness. Wallace [6] quotes experiments showing that tubers exposed to 1·8° F. of frost for 40 hrs. gave no evidence of external or internal injury but produced a greatly reduced yield. Similarly, tubers which have been heated to some extent, but not sufficiently to result in the development of wet rot, also produce weak growth. Such heating may be induced by too-rapid clamping after lifting, particularly in a warm autumn.

Seed potatoes dressed out from the clamp in spring, just before planting, usually carry long, spindly shoots that have to be removed. Secondary sprouts developing from the weakened seed are in consequence less vigorous than those from 'chitted' tubers, which produce short, sturdy primary shoots, giving more rapid early growth and greater final yield. Early vigorous plant-establishment is a very important factor in lessening the effect of eelworm attack.

Chemical deficiencies also result in weakened growth. War-time shortage of potash, for instance, was frequently responsible for defectiveness of crops, which was often wrongly attributed to eelworm. Farmers in some instances attempted to make up for this deficiency by increasing

the rate of phosphate application; this accentuated the trouble, whilst increased arable acreages with consequent reduction of livestock resulted in more minerals being sold off the farm and less returned as good dung. Blenkinsop [7] attributed the incidence of severe 'sickness' symptoms to a low potash-phosphate ratio, but although this may be true of areas where potatoes are grown on potash-deficient soils, growers of tomatoes find that 'sickness' can still occur where extremely heavy applications of sulphate of potash, which may exceed a ton per acre, are regularly applied.

Other factors such as virus infection, or drought following the planting of potatoes on dried-out dung in the rows, frequently produce symptoms not unlike those due to eelworm attack.

These various factors, which may be quite independent of eelworm infestation in the soil, are of increased importance when eelworm is present, as the weakened plants which result may show 'sickness' symptoms with a relatively light degree of eelworm infestation.

How infestation spreads.—It seems clear that the most likely means for initial infestation to reach a field is along with seed potatoes from an infested crop. O'Brien and Prentice [8] have shown that this readily occurs, and quote one sample of seed examined with an average of 15 cysts attached to each tuber. Some tubers at lifting-time show hundreds of attached cysts, many of which, however, become detached before clamping. The writer has observed patches of eelworm-infested potatoes on fields carrying their first crop of potatoes after permanent grass, and inquiries revealed that the patches were located where seed potatoes had been unloaded and sacks emptied. With succeeding potato crops, if taken at short intervals, infestation spreads by eelworm movement and by distribution during cultivation operations. Infestation is liable to spread to other fields on the wheels of implements or even on the boots of workers. Such introduction, however, is likely to be small in relation to the field as a whole and unlikely to be important except when followed by frequent cropping with potatoes.

The practice of clamping the crop on headlands of arable fields frequently introduces a focus of infestation from which cysts become distributed during cultivation.

In certain areas where early varieties of potatoes are grown, such as south Lancashire, the practice of interplanting with savoys or cauliflowers introduces the danger of cyst transportation if such plants are raised on infested land.

Some important potato-growing areas are on light sand, which is apt to 'blow' during summer gales. This is frequently a cause of eelworm-cyst distribution. In one such area in Yorkshire, examination of blown soil showed 3 viable cysts per 10 gm. of soil on the site of a Dutch-type tomato-house, which was previously known to be free from eelworm-cysts.

Flooding is also a potential means of spreading infection. No conclusive evidence on this appears to have been obtained until 1947, when investigations were made in three advisory provinces. The thawing at the end of March of that year of the heavy snow which had accumulated during the preceding 8 weeks of hard frost caused flooding of land along

the lower reaches of the rivers in many parts. Important potato-growing districts in the Eastern, East Midland, and Yorkshire–Lancashire Provinces suffered inundation and so afforded opportunities to investigate this mode of distribution. A full account of investigations carried out in these areas is in the press. In Yorkshire, samples of silt deposited on permanent grass fields were collected at 10 centres. Of these 9 were free from eelworm-cysts and 1 showed an infestation of 2 viable cysts in 40 gm. of soil. Cysts when dry are buoyant and even when waterlogged are relatively so, consequently at other centres samples of straw and other vegetable debris deposited at high-water mark were collected and examined. Eelworm cysts were found in 9 out of 12 such samples, the remaining 3 being free. The samples were taken from an area where previous surveys had indicated that 70 per cent. of the arable fields were infested with eelworm to some degree.

The general inference from these and similar examinations in the other two Provinces quoted was that there was no evidence of serious distribution of eelworm cysts on land previously free, except at the high-water mark, and that the amount of infestation introduced would be unlikely to cause 'potato sickness' at once, although close cropping with potatoes afterwards might lead to that condition.

Influence of soil types.—Successful potato-growing with high yields depends on a variety of favourable factors involving suitable climatic and soil conditions and availability of labour. Such conditions do not apply generally and consequently large-scale potato-growing has tended to become concentrated into well-defined districts where optimum conditions prevail. This concentration, together with the adoption of a shortened rotation, has led to the spread of eelworm infestation to a large proportion of arable land in the favoured districts.

Soil types in the main growing-areas are sandstone, alluvial soils, blackland, and warp. Early potatoes are normally grown on light sandy soils, which may tend to 'blow', a factor of importance if eelworm infestation is present. Main-crop varieties are usually grown on rather heavier soils where this would not apply to the same extent, whilst the heaviest types of soils are usually avoided for potato-growing. The best potato soils must be capable of deep cultivation, have a high standard of fertility, and be retentive of moisture, factors which make for quick, vigorous growth and therefore assist the plant to withstand eelworm attack.

It is generally believed that the effects of eelworm attack are more severe on light soils, and that cyst numbers are likely to be greater, and infestation remain longer than on heavier soils. Field observations over many years tend to support this belief. Triffitt [9] has shown that the transfer of infestation from a light to a heavy soil results in a decrease of cyst-size, and in consequence in egg-numbers within the cyst, so providing a check to increase of cyst-numbers in heavy soils. The greater breeding freedom in light soil is attributed to better aeration, as oxygen supply has been shown to influence the hatching rate of the eelworm larvae.

The effect of soil acidity on eelworm incidence is not clear. Peters (1926) and Morgan and Peters [10] concluded that cysts were fewer in soils

with a high pH. O'Brien and Prentice [8], however, found no difference in cyst-content in soils covering a wide range of acidity.

Control methods.—The problem of reducing 'potato sickness' has two aspects:

1. The presence of adverse conditions for growth. Any factor that reacts against healthy growth, such as a mineral deficiency in the soil, or the use of defective seed, can render the crop more susceptible to eelworm injury. Where such factors are known and can be made good the degree of crop 'sickness' in the presence of eelworm can be reduced. Thus Blenkinsop [7] found that the addition of potash to deficient soils in Devon and Cornwall reduced 'sickness' and increased crop yields. In other areas increased applications of organic manure or nitrogen have had similar effects. It should be borne in mind, however, that the effect of these improved growth conditions affects the crop only and that the consequent increase in root-growth is usually associated with a greatly increased eelworm-cyst development.
2. The direct effect of eelworm attack. Where the degree of eelworm infestation is sufficiently high, 'sickness' occurs irrespective of the state of soil fertility, and therefore to maintain satisfactory potato crops it is necessary to reduce the degree of infestation.

Trial results.—Very many attempts have been made to control 'potato sickness' by chemical means since Morgan [4] first recorded the results of a series of trials on 'potato-sick' soils. Prior to this many chemical substances had been tried on the Continent for the control of the beet eelworm (*H. schachtii*) but none had been found satisfactory from all aspects and at an economic cost. The literature on trials for the control of potato eelworm in this country is very extensive and only the main lines these trials have taken can be indicated. The effect of adding chemicals to the soil may be twofold in that either the crop or the eelworm may be affected. Some of the materials tried may therefore be grouped in accordance with the nature of the effect they produce.

Manurial treatments.—The earlier experiments of Morgan [4] consisted of soil treatment with muriate of potash, sodium chloride, nitrolim, and ground limestone, some of which benefited the crop but did not affect eelworm. Tests of calcium cyanamide have been made by Edwards [11], Miles [12], and other workers, but only extreme and completely uneconomic rates of application were found to show appreciable effect on the eelworm population. Farmyard manure applied at heavy rates has been found to give lessened 'sickness' symptoms and higher yields than equivalent quantities of inorganic fertilizers, but this was accompanied by a big increase in the cyst population in the soil.

Chemicals causing a delayed hatch.—Several chemicals have been found to delay the hatching of eelworms from the cyst, possibly because they mask the root-excretions that induce hatching. The use of naphthalene, or drained creosote salts, had been found to result in increased yields in some areas by Roebuck [13] Miles [12], Buckhurst and Fryer [14], and Edwards [11], but their action was not consistent. Bleaching powder

was also disappointing under trial. Laboratory experiments on the effect of mustard conducted by Morgan [4] and Triffitt [9, 15] indicated a delaying action on hatching from the cyst and consequent better establishment of the crop. Field trials were, however, disappointing. Following this work, Ellenby [16] described tests of allyl *iso*thiocyanate, the essential oil of black mustard, and found it to be effective, a result he attributed to delayed hatching. The method of application, however, which involved absorbing the chemical in peat for application in the rows before planting, appears unlikely to be applicable to large areas. A Yorkshire trial of this method in 1946 on tomatoes failed to reduce the cyst-content of the soil, or to benefit the crop in any way.

Chemicals aiming at cyst-destruction.—O'Brien and Prentice [8] obtained a good effect on the crop from the use of calcium cyanide at 6 cwt. per acre, and Miles [12] obtained a slight crop increase by using this material, but the cyst-content of the soil was not greatly reduced. Carbon bisulphide has also been used on potatoes and tomatoes without very satisfactory results. Tomato crops have been found to fail in heavily infested houses in spite of injections of carbon bisulphide. Investigations are still continuing on the efficiency in this country of a soil fumigant known as D.D., which is a mixture of dichloropropane and dichloropropylene. This material has been found effective in controlling various species of eelworm in America. Marked crop benefit has been observed in this country on potatoes following its use. Some degree of egg-kill certainly occurs, but it is not complete, and it seems possible that the improvement of the crop may in part be due to a partial sterilization effect.

Other chemicals such as ammonium and calcium *iso*thiocyanates and phenyl *iso*thiocyanate have been used with some success in small-scale experiments, but appear unlikely to be practicable for large-scale use because of their phytocidal characteristics and prohibitive cost.

Biological control.—Following observations on the effect on soil cyst-population of early as against late lifting, O'Brien and Prentice suggest broadcasting and ploughing in chats as a trap-crop immediately following the lifting of early potatoes. After about 50 days' growth and before cyst-formation begins, the plants should be lifted and removed. Carroll and McMahon [17] investigated the use of two trap crops of potatoes and concluded that infestation could be reduced appreciably by this method if the plants were completely removed before cyst-formation began. This procedure would not, however, appear capable of application for large-scale use. Investigations by Triffitt [18] and Franklin [19] indicated that larval emergence from the cyst could be stimulated to some extent in the absence of potatoes by the root-secretions of maize and certain grasses, particularly rough- and smooth-stalked meadow grasses (*Poa trivialis* L. and *P. pratensis* L.), but up to now there appears to be no clear indication of the extent to which this will occur under field conditions.

Control in tomato-houses.—Control of eelworm attack on tomatoes is relatively easy. The high value of the crop justifies the use of expensive methods, some of which cannot be used on potato land. Good crops can be ensured in infested houses by steam sterilization or by replacing the

surface-soil to a depth of 15 in. by clean soil. Either of these methods, if carefully and correctly carried out, will allow two tomato crops to be taken before further treatment is necessary. Many attempts have been made to obtain control by chemical means, but so far no really satisfactory alternatives to these two methods have been found. The material known as D.D. is the most promising of the chemicals tried under glasshouse conditions, but although its use results in very striking crop improvement in most cases it does not appear, as applied so far, to have any effect in reducing the cyst-population of the soil. At several centres, however, for the past 2 years the writer has seen good successive crops of tomatoes on heavily infested soil which had been treated with D.D. each year before planting. Crops on control plots at these centres failed.

In Dutch-type houses the usual alternative to soil changing is to remove the whole structure to a new site. This operation is cheaper than steaming and is often effective for a long period.

Field surveys for advisory purposes.—Owing to the pressing national need during and after the war for growing very large acreages of potatoes, and to the existing lack of chemical or biological means of ridding land of eelworm infestation, it was realized that farmers should be assisted in areas where eelworm is prevalent. An attempt has therefore been made to help in the selection of suitable fields for cropping with potatoes by means of a soil-sampling and cyst-counting technique. Whilst many factors may be involved in producing 'potato-sickness' condition, all investigators agree that eelworm is always involved. It is considered, therefore, that a knowledge of the degree of soil infestation is of great assistance to the grower in the planning of a cropping programme. It is claimed that forecasts of the probable effect on a crop of a known degree of infestation may be made with a fair degree of accuracy in most cases. Where relatively small areas in a field are heavily infested this would not show up in the cyst-count obtained from a bulk sample, but as the crop from the field as a whole would be satisfactory, for practical purposes the forecast would be sound.

Bulk samples are made up of a series of roughly equally spaced borings, but including any areas where previous patchiness was reported in the field to be examined, and are taken at the rate of 50 per field of 10 acres or less. The bulk sample is air-dried in the laboratory, worked down fine by hand, and passed through a 2-mm. sieve to remove stones and vegetable debris. It is then very thoroughly mixed and from it 4 unit samples of 10 gm. each are drawn. These are then shaken up in water in conical flasks. After thorough shaking the flasks are filled to the brim and cysts and other floating material removed to slips of blotting-paper. The cysts are then picked off, placed on slides in series, crushed, examined microscopically, and the final count of viable and non-viable cysts expressed as the numbers in 10 gm. of soil as sampled. Cysts containing a fairly large number of eggs and larvae in good condition are regarded as viable.

Information on the history of the field is obtained, as far as possible, when soil samples are collected, particularly the date and character of the previous potato crop, and advice on future cropping is based on this,

together with the cyst-count obtained. The effect of different degrees of infestation has been studied over a period of years, and from this it has been concluded that with a viable cyst-population below 5 per 10-gm. sample a satisfactory crop of potatoes can usually be obtained if other factors are favourable, although a dangerous cyst-increase may occur. The usual practice adopted is to sample all available fields on the farm and from the cyst-counts obtained select those most suitable for cropping with potatoes.

It is clear that when once land becomes infested with eelworms the cyst-population can soon increase to a dangerous degree unless care in cropping is exercised. Miles and Miles [20] showed that 2 heavy crops of potatoes in 4 years raised the count from 1 cyst to 94 cysts per 100 c.c. of soil. Cyst-counts made in Yorkshire before and after the 1948 crop show that relatively low counts may build up to a serious extent after one crop. Results representing the mean count per 10-gm. soil sample obtained at 4 centres are given in Table 2.

TABLE 2. *Mean Count of Cysts per 10 gm. of Soil*

	Years since last potato crop	*Before cropping*		*After cropping*	
		Total cysts	*Viable cysts*	*Total cysts*	*Viable cysts*
Centre 1	6	4·0	1·5	8·25	4·5
,, 2	6	10·0	4·5	12·0	7·0
,, 3	4	4·75	2·5	12·5	7·75
,, 4	6	7·25	3·0	12·25	7·0

Counts at all 4 centres have now reached or exceeded the danger mark of infestation, although 3 out of the 4 fields had been rested from potatoes for 6 years.

Early workers found that when 'potato sickness' developed, a rest from potatoes for 3 or 4 years was sufficient to ensure safety for a succeeding crop. It is clear that this does not apply for heavy infestations. Analysis of cyst-counts made from 804 fields in Yorkshire for the 1948 crop, and where the previous history of the field was known, show that very lengthy rests may be necessary to ensure that the degree of infestation will be reduced sufficiently to render a further crop safe. An analysis of figures obtained indicating the persistence of infestation is given in Table 3.

Table 3, however, does not give a completely true picture of the number of fields dangerously infested, as although viable eggs are still present in the cysts after 7 or 8 years, the number per cyst is much less than in more freshly formed cysts. Allowance is made for this in giving advice on cropping. Serious infestation can, however, persist for many years; crops showing heavy attack in patches have been observed in fields after a rest of 10 years from potatoes where the original infestation was very high, and counts of 2 to 3 viable cysts per 10 gm. of soil have been obtained from fields that have carried no potatoes for 13 years.

Cropping infested land.—The only practicable means available at present for maintaining potato crops at a satisfactory level is to follow a cropping system that will not result in an increase of eelworm infestation

TABLE 3. *Persistence of Infestation in 804 Yorkshire Fields*

No. of years' rest	*No. of fields*	*Range of viable cyst-population*	*Viable cysts (mean)*	*Total cysts (mean)*	*No. with 4 or more viable cysts*
8	30	0·25–4·25	1·75	2·23	3
7	42	0·25–7·5	1·43	2·48	4
6	82	0·25–27·5	1·49	2·96	8
5	127	0·25–22·5	1·84	3·41	17
4	159	0·25–15·75	1·74	3·35	25
3	157	0·25–21·5	3·02	4·75	42
2	89	0·25–60·0	3·32	4·78	21
1	83	0·25–71·0	5·35	7·87	26
0	35	0·50–23·5	6·02	8·6	15

in the soil. This would mean in many instances lengthening the existing rotation. Under conditions where potato production is largely confined to a relatively small part of the country, the adoption of a wider rotation is often difficult. The first and, on a long-term basis, the most satisfactory means of dealing with the problem would be to extend the growing-areas. Good potato crops can be grown outside the areas where they are now mainly grown, and an increased potato acreage on the general mixed farm would have many obvious advantages. In the past, availability of labour for planting and lifting the crop was to some extent a limiting factor to this procedure, but of late years it has been shown that labour can often be transported satisfactorily to where it is needed. This factor, therefore, should no longer be considered an insuperable difficulty. Possibly a greater obstacle to altering the cropping system in existing potato-growing areas is that many of the farms in these areas are almost wholly arable, frequently without either adequate buildings or water in the fields for stock, so that a major change in farming policy would be extremely difficult. Where this can be got over, the use of leys would allow a wider rotation to be adopted, and the introduction of more stock would make more dung available for the maintenance of soil fertility.

The second approach to the problem, assuming that the main potato-growing areas will have to continue to grow large acreages of this crop, is to accept the presence of the eelworm as a normal factor. It may then be possible to maintain yields at a satisfactory level by extending the rotation in fields known to be infested with eelworm and by paying increased attention to building up soil fertility, together with taking precautions to reduce the spread of infestation. On this latter point the possibility of having permanent clamp sites away from the fields where potatoes are grown should be considered. It is a great convenience to clamp potatoes on the headland of the field where the crop is grown, but in the presence of eelworm this is outweighed by the concentration of infestation built up on the sites that will be cultivated later. The use of tubers from an infested crop as seed should also be avoided, as being a source of danger.

It seems possible that the date of lifting the crop may have an important effect on the rate of cyst-increase in the soil; this applies particularly

to early varieties, and may have an influence on cropping in some districts. Morgan [4] found a rapid increase in cyst-content on land in Lincolnshire which was regularly cropped with early or second early varieties, but O'Brien and Prentice [8], in describing Ayrshire conditions, where the lifting of early varieties begins early in June, state that by this time cysts are still immature and are only just beginning to appear externally on the roots. They considered that a big proportion of the cysts might fail to reach maturity. This could, however, apply only to a few sheltered very early districts, as in most potato-growing areas lifting does not start until July, by which time a big proportion of the cysts has reached the brown stage and these cysts readily fall off into the soil.

Isolated fields showing heavy eelworm infestation are occasionally met with in areas where a small acreage of potatoes is grown. This often occurs on heavy land and is bound up with the question of accessibility. Road-side fields, from which the crop can be removed readily in a wet autumn, tend to be cropped with potatoes far more frequently than a less accessible field, and consequently may build up a dangerous degree of infestation.

In some areas where infestation by eelworm is general, a satisfactory alternative crop to potatoes has yet to be found. Sugar-beet has sometimes proved an excellent substitute but can only be grown to a limited extent generally. Where it is not possible therefore, in infested areas, to increase grassland and stock as an alternative to intensive arable cultivation, it may be necessary to consider other crops outside the present range of farm crops as a means of lengthening the rotation and resting infested land.

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